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AFFDL-TR-68-115

**COMPUTER PROGRAMS FOR THE PREDICTION  
OF AIRCRAFT TAKE-OFF PERFORMANCE  
ON CLAY AND SAND AIRFIELDS**

*ALFRED L. SHARP*

AD853652

TECHNICAL REPORT AFFDL-TR-68-115

APRIL 1969

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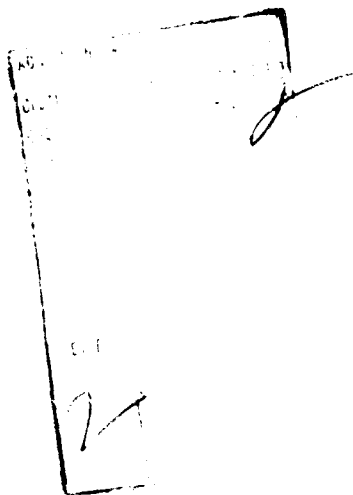
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**COMPUTER PROGRAMS FOR THE PREDICTION  
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## FOREWORD

This research was performed by the Aerospace Dynamics Branch, Vehicle Dynamics Division, Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio. The research was conducted in support of a continuing effort to obtain advanced data and develop techniques for predicting dynamic loads in flight vehicles under the Air Force Systems Command's exploratory development program. The research was initiated under Project 1370, "Dynamic Problems in Flight Vehicles", Task 137008, "Prediction and Prevention of Aircraft Dynamic Loads".

This report covers work conducted from September 1967 to May 1968.

The manuscript was released by the author in June 1968 for publication as a technical report.

This technical report has been reviewed and is approved.



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## ABSTRACT

A prediction method for estimating wheel sinkage, landing gear drag and aircraft take-off performance on clay and sand airfields, of various bearing strengths, is described. Estimates of take-off distance, wheel drag to vertical force ratios for the full ground velocity range, and the wheel sinkage into the soils have been prepared for the C-5 and C-141 aircraft. These charts have been prepared for various aircraft operating gross weights and selected tire pressures. Results indicate that the C-5 airplane can operate successfully at a gross weight of 571,000 pounds, with 95 PSI tire pressure, from soil airfields having a bearing strength of  $\text{CBR} = 5$ . The take-off distance is increased by 20% over paved surfaces and the maximum wheel sinkage into the soil is about 1.2 inches. The C-141 airplane can operate at a gross weight of 280,000 pounds, with 100 PSI tire pressure, from soil airfields having a bearing strength of  $\text{CBR} = 5.5$ . The increase in take-off distance is about 20% greater than for paved surfaces and the maximum wheel sinkage into the soil is about 1.8 inches.

Three FORTRAN IV computer programs, SOLDG, SOLDG2 and TAKOFF for computing landing gear drag, have been prepared and are listed in the report. SOLDG is employed when only the weight and tire configuration are known and SOLDG2 requires knowledge of the airplane aerodynamic lift and landing gear geometry. Both of these programs assume constant taxi velocities. TAKOFF is a more sophisticated program which requires knowledge of the airplane aerodynamic lift, landing gear geometry, and power plant thrust and is used to compute take-off distances. Example problems using each of the computer programs are illustrated.

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## SYMBOLS

$a$	acceleration (ft/sec <sup>2</sup> )
AI	airfield index
$A_t$	tire footprint area (in <sup>2</sup> )
B	tire width (in)
CBR	California Bearing Ratio
$C_D$	aerodynamic drag coefficient
$C_{D_I}$	soil impingement drag coefficient
$CI_{avg}$	average of cone index readings taken
CI	cone index (psi)
$CI_{eff}$	effective soil strength when corrected for dynamic sinkage
$C_L$	aerodynamic lift coefficient
$C_{L_{max}}$	maximum aerodynamic lift coefficient
$C_{L_t}$	tire lift coefficient
$D_a$	aerodynamic drag
D	outside diameter of undeflected tire (in)
DF	dynamic factor at zero sinkage
$D_I$	drag resistance due to soil impingement effects
$D_R$	low speed rolling resistance
$F_D$	landing gear drag

# SYMBOLS (Cont'd)

$F_{DM}$	total main gear soil drag (lb)
$F_{DN}$	total nose gear soil drag (lb)
$F_{DT}$	soil drag for a single set of tandem wheels (lb)
$F_{DS}$	soil drag for a single tire
$F_V$	vertical wheel load (lb)
$G$	average rate of increase in cone index, averaged over a depth equal to one-half the tire width (psi/in)
$G_{eff}$	effective soil strength when corrected for dynamic sinkage
$g$	acceleration due to gravity (ft/sec <sup>2</sup> )
$h_t$	tire section height (in)
$L_a$	aerodynamic lift
$L_I$	tire lift due to impingement drag
$l_t$	tire footprint length (in)
$m$	mass
$N_T$	number of tandem wheel sets per side
$N_W$	number of tires per side
$PI$	percent increase in takeoff distance
$q_s$	dynamic soil pressure (psi)
$R_N$	total nose gear vertical load
$R_M$	total main gear vertical load
$S$	wing area (sq ft)
$S$	area over which either tire lift or tire drag forces are assumed to act (sq in)

# SYMBOLS (Cont'd)

T	engine thrust
$t_p$	impulse duration or pulse time: time a soil element is under a wheel (sec)
TWF	tandem wheel factor
V	forward velocity (ips, fps, or kn)
$V_{to}$	velocity required for takeoff
$V_p$	tire planing velocity (ips or kn)
$V_{stall}$	stall speed
W	gross weight
WES	U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.
Z	soil sinkage (in)
$Z'$	dynamic soil sinkage (in)
$\overline{ZA}$	vertical axle displacement (in)
$\delta_t$	tire deflection (in)
$\kappa$	takeoff speed safety margin
$\mu$	rigid surface rolling-resistance coefficient
$\mu_1^*, \mu_2^*$	first and second pass low speed drag coefficient
$\rho_s$	soil density (lb/sec <sup>2</sup> /ft <sup>4</sup> )
$\Sigma F$	sum of forces
$\phi$	runway slope (rad)
$n_c$	clay mobility number
$n'_c$	dynamic clay mobility number
$n_s$	sand mobility number
$n'_s$	dynamic sand mobility number

## SECTION I

### INTRODUCTION

Operating of aircraft from minimum length runways with substandard strengths has been given increased emphasis in view of present operational requirement estimates. In anticipation of forthcoming requests for methods to predict loads and performance of aircraft operating in remote areas where good, long, hard surfaced runways would not be available, a program was initiated in 1964 with The Boeing Company to provide some analytical means by which these performance estimates could be made. This study has recently been completed and as such, provides the first analytical model available for the prediction of aircraft soil drag, sinkage and takeoff performance on clay and sandy type soils.

Various techniques were used to predict soil static and dynamic effects, however, the method which was finally considered to give the best correlation with available data was basically one developed by the U.S. Army Waterways Experiment Station (WES) modified for high speed effects. This method uses empirical sinkage data obtained by towing carts with various loads and various tire sizes over especially prepared soil beds. The results were collapsed into a dimensionless number called the Mobility Number which is a function of the wheel, the load and the soil strength characteristics.

The basic Mobility Numbers were modified by Boeing to account for dynamic effects not covered by the original relationships. They were then used to determine analytically the performance of the 367-80 aircraft (KC-135 prototype) and compare these results to a high-flotation test conducted on Harper's dry lake.

The purpose of this technical report is to present three programs for automating the methods generated by Boeing and WES and to calculate the performance capability of two other first line cargo type aircraft (C-141 and the C-5) while operating on runways of varying soil strength.

The three programs cover varying levels of detail which may be required. The first is used to calculate drag and sinkage for wheels attached to one strut while taxiing at constant speed. The second considers the complete aircraft taxiing at constant velocity and the last calculates takeoff performance of a complete aircraft on hard surface (paved runways) and on clay and sandy soils. The computer programs were tested for accuracy by analyzing conditions which were identical to those used by Boeing and comparing the results with Boeing's full scale airplane tests at Harper Lake. These results were identified as "FDDS Correlation."

Finally, a discussion is given of the limitations of the method and of ways by which improvements may be achieved.

## SECTION II

### DESCRIPTION OF MODEL

1. Discussion - Although Reference 1 gives a detailed development of the analytical wheel-soil model, a summarized description is given here for completeness.

Drag loads resulting from a tire rolling on a soft, yielding soil can be considered to be made up of two interrelated components, a static (low speed) and dynamic (high speed) effect. The equations used in the TAKOFF program will be derived from basic relationships. The other two programs, SOLDG2 and SOLDG, are merely formed as special cases of the general development.

An aircraft accelerating under the thrust of engines obeys the familiar relation:

$$\Sigma F = ma$$

where

$\Sigma F$  = The sum of all external forces in the plane of the motion

$m$  = Mass of the body

$a$  = The body's acceleration resulting from the applied forces.

The forces making up the  $\Sigma F$  can be seen in Figure 1. The problem in the present study is to determine the drag forces associated with the landing gear ( $F_{D_N}$  and  $F_{D_M}$  in the figure). The other forces will be discussed later.

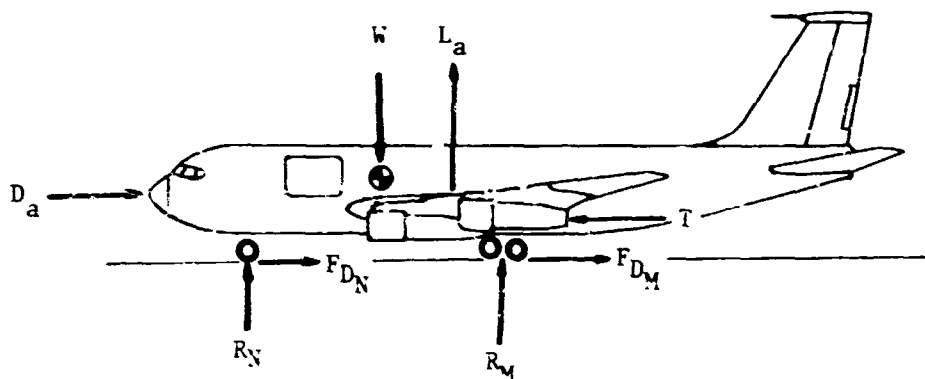


FIGURE 1 Forces Acting on an Aircraft While Taxiing

On paved surfaces these forces are merely the coefficient of rolling friction  $\mu$  (usually taken as 0.02 or 0.03 for paved surfaces) times the normal force or ground reactions  $R_N$  and  $R_M$ . On soil, however, a more difficult problem exists. Figure 2 shows a tire traversing a soil surface. As one would expect, the sinkage and consequently the force required to move the wheel is greatly affected by the speed of the vehicle.

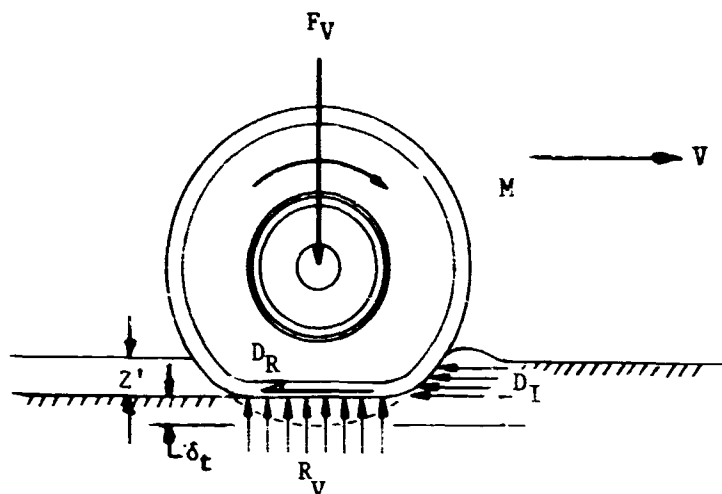


FIGURE 2 Tire Traversing a Soil Surface

As mentioned above, two drag forces make up the total drag of the wheels. In Figure 2,  $D_R$  is the low speed rolling resistance force and  $D_I$  is the high speed impingement drag force. These forces will be discussed separately, although some interaction exists because both are functions of some of the same parameters.

**1.1 Soil Strength** - Before discussing the details of these drag forces, a few words are in order to describe the basis for determining soil strength. In this study and in much of the work being done in soil mechanics, strength is measured by the California Bearing Ratio (CBR) which is a measure of the resistance to penetration that the soil exhibits to a cylinder of three sq. in. area. That is, a piston or bearing plate is subjected to an increasing load and deformations are noted. The ratio of the bearing load per unit deformation to the deformation of a standard soil (California limestone gravel) in percent is the CBR. Details of CBR measurements are in accordance with MIL-STD-621. Because of the difficulty in making CBR measurements, WES

developed the airfield penetrometer which is a device consisting of a 30-degree cone with base area of 0.196 square inches mounted on the bottom of a graduated rod. When the penetrometer is forced into the ground, a dial gage mounted on top of the rod gives a measure of the force required to penetrate the soil. The reduced readings of this device are known as Airfield Index (AI). The Cone Index (CI) which is used in the following formulations is based on an identical procedure as that of AI except that the scale and cone area are different. The scale used in CI measurement (0 - 300) represents a force of 0 - 150 pounds which results from a cone having an area of 0.50 square inches. Obtaining CI directly requires too much effort for hand penetration thus, the Airfield Index requiring about one-fifth the effort was adopted. Conversion from AI to CI is merely a scale change and is a 1 to 50 ratio. Conversion from CBR to AI is approximately a 1 to 1 ratio, however, this may vary widely and caution should be used in manipulating CBR and CI to avoid errors in conversion. Figure 3 shows typical plots of AI and CBR. Notice that values range from .45 to 1, to 1.4 to 1, for CBR to AI ratios. It would be advisable to measure CI directly and avoid the conversion altogether. Boeing indicates that if the AI and CBR are known, the conversion to CI can be made using the 50 to 1 ratio mentioned above, but if only CBR is known, an approximate and widely accepted conversion is 1 to 40. This value will, however, underpredict sinkages as given by the present method, and a more realistic ratio of about 1 to 25 CBR to CI should be used. In the present studies, an assumption is made that CI is known, or that when a correlation is made for the 367-80 data on a soil measured in CBR, a 36 to 1 conversion is used to conform with the Boeing assumptions.

1.2 Sinkage - One other parameter which must be discussed before the drag terms can be defined in detail is sinkage. Sinkage relationships used in the present study are obtained from WES empirical data generated by towing weighted carts through soils of various CI using a wide variety of tire geometry. This data was collapsed into a non-dimensional term called "Mobility Number".

$$\Omega_c = \frac{(CI) B D}{F_v} \left( \frac{\delta_t}{h_t} \right)^{1/2} \text{ for clay} \quad (1)$$

and

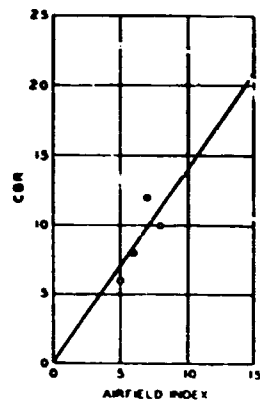
$$\Omega_s = \frac{G(B D)^{3/2}}{F_v} \left( \frac{\delta_t}{h_t} \right) \text{ for sand} \quad (2)$$

where

$\Omega_c, \Omega_s$  = Mobility Numbers for clay and sand respectively

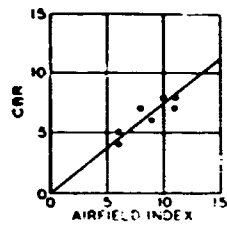
CI = Cone Index (Psi)

B = Width of Tire (in.)



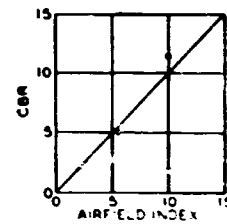
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Fort Leonard Wood, MO.



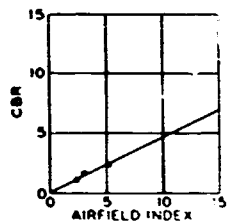
Site U-8

Fort Campbell, KY.



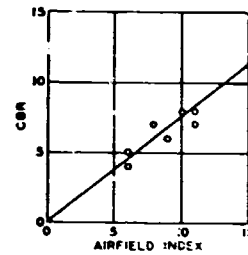
Site U-5

Fort Stewart, GA.



Site U-11

Yuma Proving Ground, Arizona



Site U-9

Fort Campbell, KY.

FIGURE 3 CBR - Airfield Index Correlation

D = Diameter of Tire (in.)

$\delta_t$  = Tire Deflection Caused by  $F_V$  on a rigid surface (in.)

$h_t$  = Tire Section Height (in.)

$F_V$  = Vertical Force on a Single Tire (lb.)

G = Slope of CI vs Depth Curve (Psi/in) =  $2 CI_{avg}/B$

Using these equations, values of  $\Omega_c$  and  $\Omega_s$  were plotted against an incremental sinkage coefficient  $Z/D$  for three passes over the same path. Equations were then generated to fit these data for a range of mobility numbers. The resulting curves are shown on Figures 4 and 5 for the first two passes. For the present study, only first pass sinkage data will be used.

$$\frac{Z}{D} = \frac{0.1208}{\Omega_c - 0.9468} - 0.0095 \quad \text{for clay} \quad (3)$$

and

$$\frac{Z}{D} = \frac{0.3439}{\Omega_s - 0.6239} - 0.0017 \quad \text{for sand} \quad (4)$$

These equations are valid for  $\Omega_c$  from 2.0 to 11.0 and  $\Omega_s$  from 3.5 to 82.5, respectively. Accuracy is affected most in the lower range as can be seen from the figures.

Since these data were obtained at a very slow towing velocity, some consideration must be given to the dynamic effects if sinkages at higher velocities are to be valid. This was done by fitting an equation through experimental data to determine a factor which when multiplied times the slow speed sinkage gives the high speed dynamic sinkage. The equation for this dynamic factor is:

$$DF = 1.0 + 1.34e^{-1.27t_p} \quad (5)$$

where

DF = Dynamic Factor

$t_p$  = Pulse time or time of application of deforming force =  $\frac{l_t}{V}$  (sec)

where

$l_t$  = Tire Footprint Length (in.)

V = Ground Velocity (in./sec)

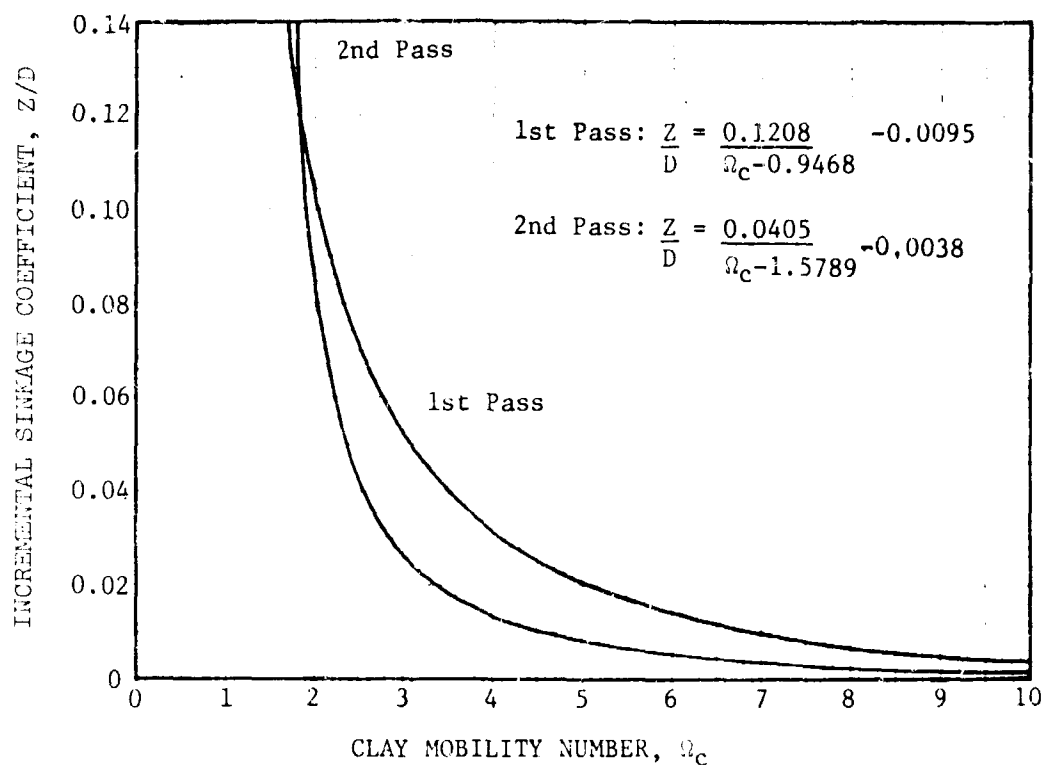


Figure 4 Incremental Sinkage Coefficient for Clay

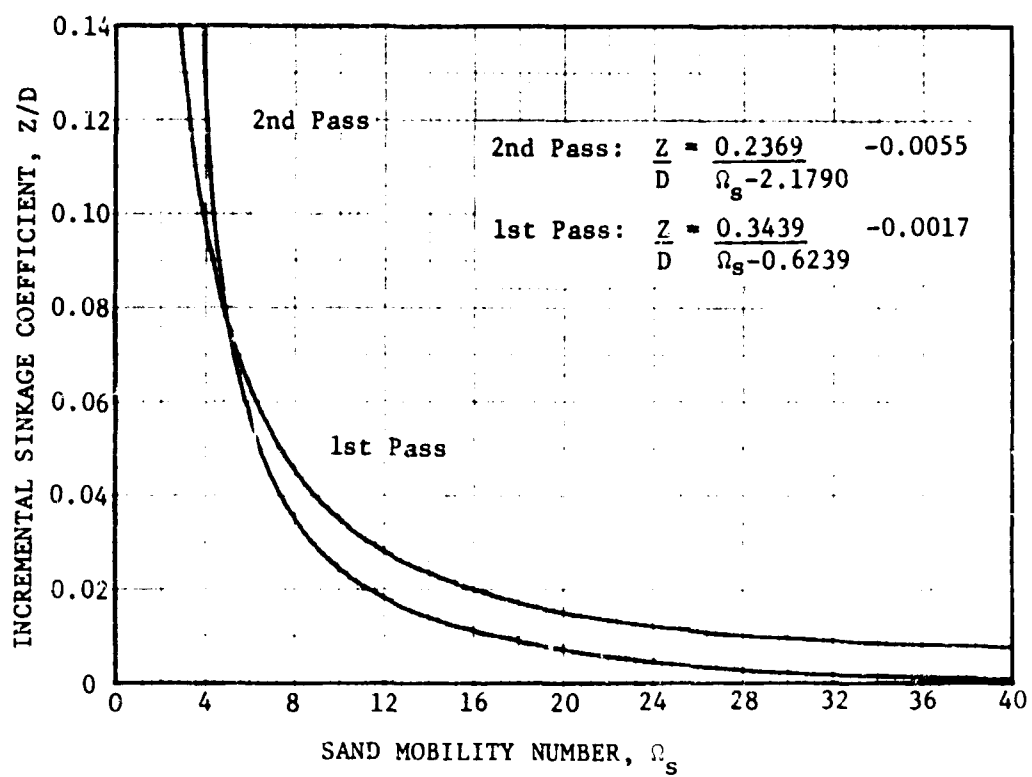


Figure 5 Incremental Sinkage Coefficients for Sand

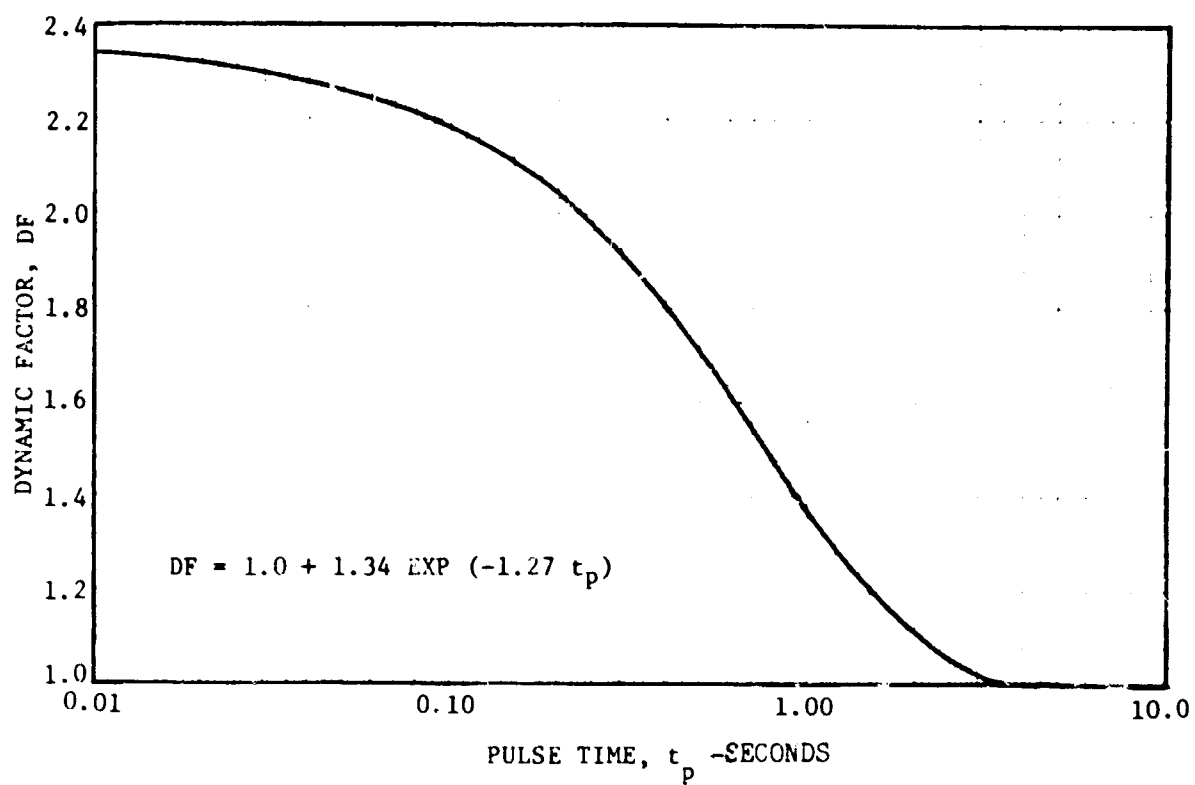


Figure 6 Dynamic Factor as a Function of Pulse Time

In the equation for pulse time, the footprint is a function of the axle displacement and becomes:

$$l_t = 2 \left[ D \cdot \bar{Z}A - \bar{Z}A^2 \right]^{1/2} \quad (6)$$

where

$D$  = Tire Diameter (in.)

$\bar{Z}A$  = Axle Displacement =  $\delta_t + Z$  or tire deflection

The variation of dynamic factor with pulse time is shown in Figure 6. Using the dynamic factor, an effective soil strength is determined by modifying the CI or G of the soil as follows:

$$CI_{eff} = \frac{DF \cdot CI}{1.6} \quad (7)$$

$$G_{eff} = \frac{DF \cdot G}{1.6} \quad (8)$$

In equations 7 and 8, the 1.6 is used to correct the basic WES data for the very slow towing speeds. This addition of the dynamic effect now allows us to consider the mobility number as a dynamic mobility number and gives the corrected sinkage coefficients from Figures 4 and 5. The equation becomes:

$$\frac{Z'}{D} = \frac{0.1208}{\Omega'_c - 0.9468} - 0.0095 \quad \text{for clay} \quad (9)$$

and

$$\frac{Z'}{D} = \frac{0.3429}{\Omega'_s - 0.6239} - 0.0017 \quad \text{for sand} \quad (10)$$

where

$Z'$  = Dynamic Sinkage (in.)

$D$  = Tire Diameter (in.)

$\Omega'_c$  = Dynamic Clay Mobility Number =  $\frac{DF}{1.6} \cdot \Omega_c$

$\Omega'_s$  = Dynamic Sand Mobility Number =  $\frac{DF}{1.6} \cdot \Omega_s$

Calculation of dynamic sinkage is an iterative process since the dynamic factor is a function of the soil sinkage. The present program assumes an initial sinkage value and iterates, continuously updating the assumed value until the calculated sinkage is within a specified percentage of the assumed sinkage. The process converges quite rapidly to the actual sinkage.

Once the sinkage values are determined, the drag components can be determined. The next section discusses the procedure for determining these parameters.

## 2. Soil Drag

In the previous discussion, two types of soil drag were briefly mentioned - the low speed or rolling resistance drag and the impingement or high speed drag. This section will discuss each type individually although an interaction can be observed.

2.1 Low Speed Drag - The drag contributed by low speed sinkage, friction or rolling resistance considerations can be compared to the classic friction drag calculated by multiplying the normal force by some friction coefficients (usually 0.02 or 0.03 for paved surfaces) as seen in Equation 11.

$$F_D = F_N \cdot \mu \quad (11)$$

The coefficient  $\mu$  is then the ratio of the drag force over the vertical force. The soil drag was determined for the present method from additional WES empirical drag ratio or drag coefficient data gathered from low speed tow tests of configurations given various mobility numbers.

Curves fitted through these data are shown as Figures 7 and 8 for clay and sand. These curves can be represented by the following equations. For clay soil on the first and second pass:

$$\frac{F_D}{F_V} = \mu^* = \frac{0.4072}{\Omega_c - 0.8713} - 0.0206 \quad (12)$$

and for sandy soil on the first pass:

$$\frac{F_D}{F_V} = \mu_1^* = \frac{0.6490}{\Omega_s - 2.2222} + 0.0366 \quad (13)$$

and on the second pass:

$$\frac{F_D}{F_V} = \mu_2^* = \frac{0.7085}{\Omega_s - 2.1739} + 0.0195 \quad (14)$$

Dynamic effects are again considered by applying the dynamic factor as before and substituting the dynamic mobility number for  $\Omega_c$  and  $\Omega_s$ , in equations 12 and 13.

2.2 High Speed Drag - The high speed drag contribution is determined by assuming that soil drag is analogous to other types of fluid flow in that it varies proportionally to the frontal or flat plate area which the tire presents to the soil. This drag is formulated using the familiar equation

$$D_I = C_{D_I} qS \quad (15)$$

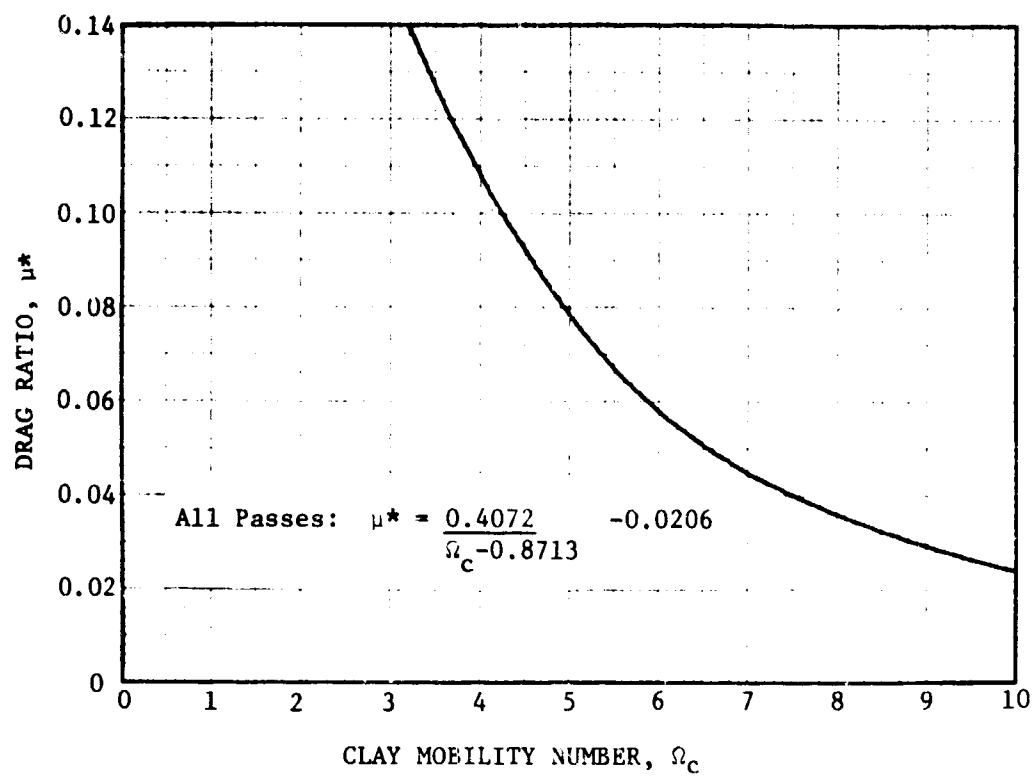


Figure 7 Drag Ratio for Light Loads on Clay

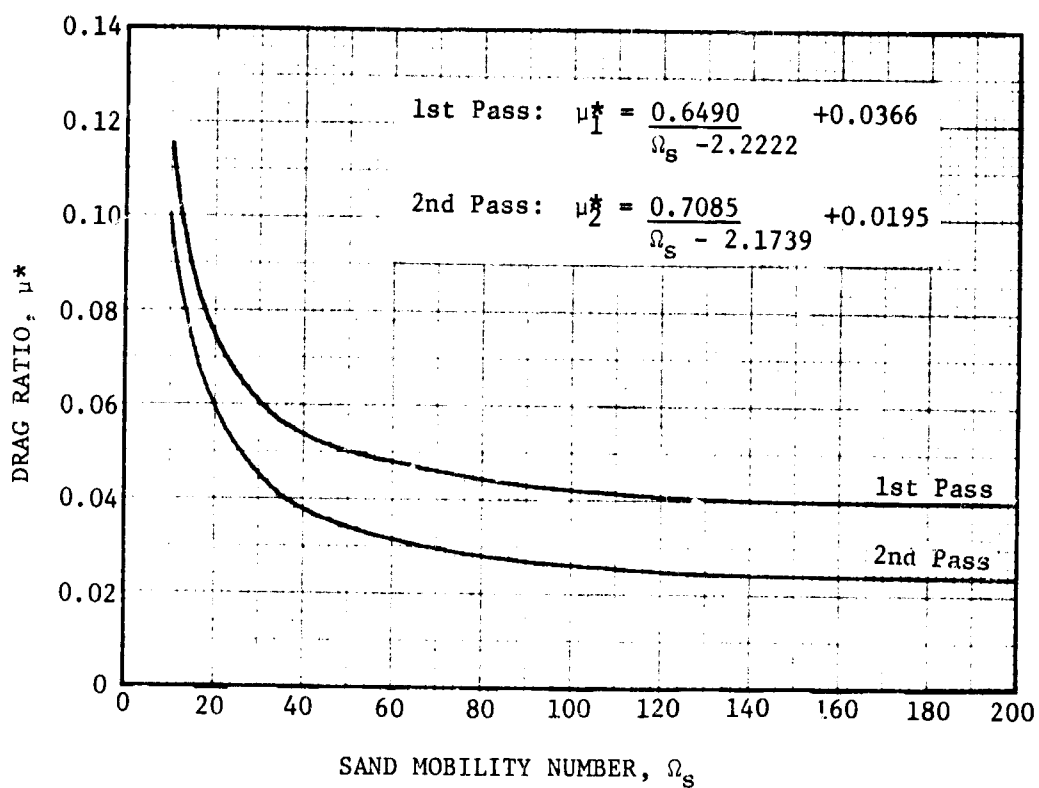


Figure 8 Drag Ratio for Light Loads on Sand

where

$D_I$  = Impingement Drag (lb.)

$C_{D_I}$  = Impingement Drag Coefficient

$q$  = Dynamic Pressure of Soil (Psi) =  $1/2 \rho_s V^2$

$\rho_s$  = Soil Density (lb/sec<sup>2</sup>/in<sup>4</sup>)

$V$  = Forward Velocity (ips)

$S$  = Tire Frontal Area =  $B \cdot Z'$

An illustration showing the area over which the drag is applied is given in Figure 9a. Using this basic assumption, a series of empirical  $C_{D_I}$  values were determined such that the equation is satisfied. The

drag indicated by Equation 15 reaches a limit at some velocity by a lifting effect caused by the tire planing over the soil. The velocity where planing is experienced is calculated by assuming that the lift experienced by the tire follows a similar relationship:

$$L_T = C_{L_T} q S \quad (16)$$

where

$L_T$  = Lift due to impingement drag (lb) =  
Vertical Tire Force  $F_V$

$C_{L_T}$  = Soil Lift Coefficient

$q$  = Dynamic Soil Pressure (psi) =  $1/2 \rho_s V_p^2$

$A_t$  = Area over which  $F_V$  is distributed

$\rho_s$  = Soil Density (lb/sec<sup>2</sup>/in<sup>4</sup>)

$V_p$  = Tire Planing Velocity (ips)

Rearranging Equation 16 and solving for  $V_p$  we have:

$$V_p = \sqrt{\frac{2F_V}{A_t \rho_s C_{L_T}}} \quad (17)$$

An illustration showing the area over which the lift force is assumed to act is given in Figure 9b. Experimental values of  $C_{LT}$  to cause

planing for various soil strengths were determined from Boeing's Harper Lake test series and are shown in Figure 10. The planing velocity effect on the impingement drag coefficient is shown in Figure 11. More discussion of these curves is given in Section 7.

**2.3 Total Soil Drag** - The total soil drag can now be determined from the components given by paragraph 2.1 and 2.2 by applying them to each tire of the vehicle and summing up to obtain the total drag. The only exception to this is when the geometry is such that a tandem set exists. Then the drag of the leading tire is calculated and the drag of the trailing tire is assumed to be a percentage of the leading tire. This slight simplification has proved to be a reasonable representation of the drag values. The total drag for a set of main landing gear then becomes

$$F_{D_M} = F_{D_T} \cdot N_T \cdot 2 \quad (18)$$

for tandem wheel sets and

$$F_{D_M} = F_{D_S} \cdot N_W \cdot 2 \quad (19)$$

for single or dual wheel sets.

In Equations 18 and 19:

$F_{D_M}$  = Total Main Landing Gear Drag (lb)

$F_{D_T}$  = Soil drag for a single set of Tandem Wheels (lb)

$N_T$  = Number of Tandem Wheel Sets per Side

$F_{D_S}$  = Soil Drag for a Single Tire (lb)

$N_W$  = Number of Tires per side.

The terms  $F_{D_T}$  and  $F_{D_S}$  are formed from the components of low and high speed drag mentioned in the preceding paragraphs and are given by equations 20 and 21.

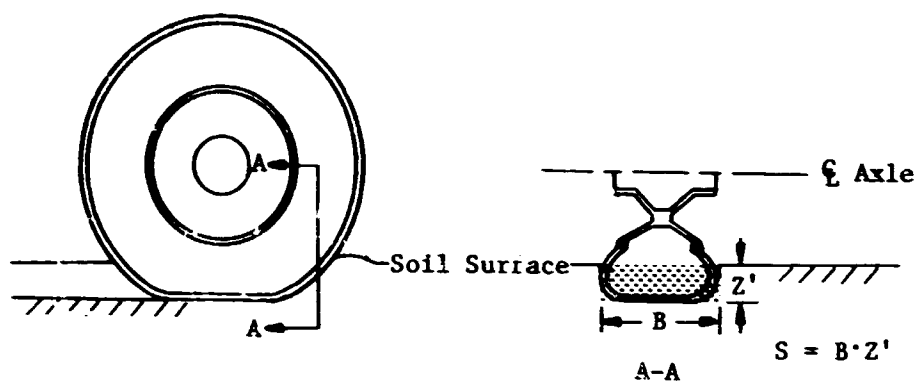


Figure 9a - Drag Area

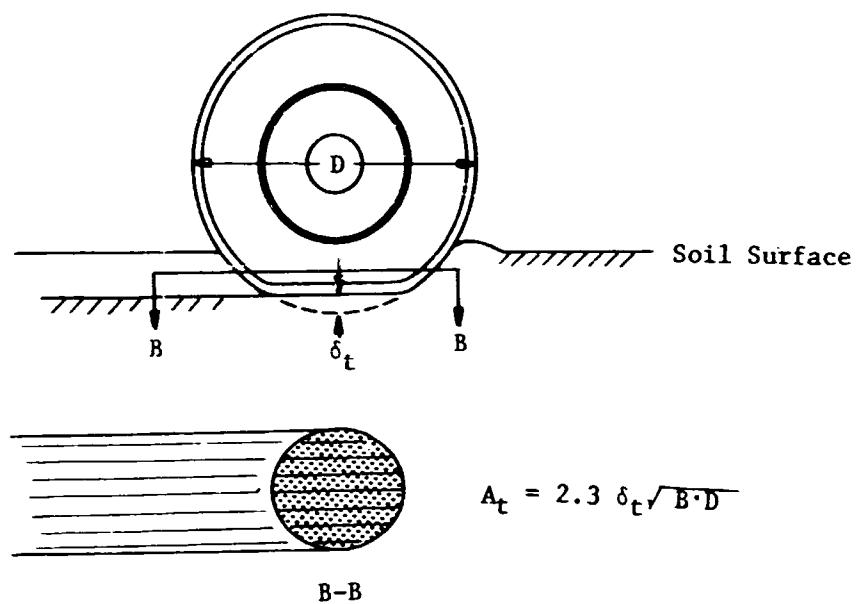


Figure 9b - Lift Area

Figure 9 Areas Used in Soil Lift and Drag Equations

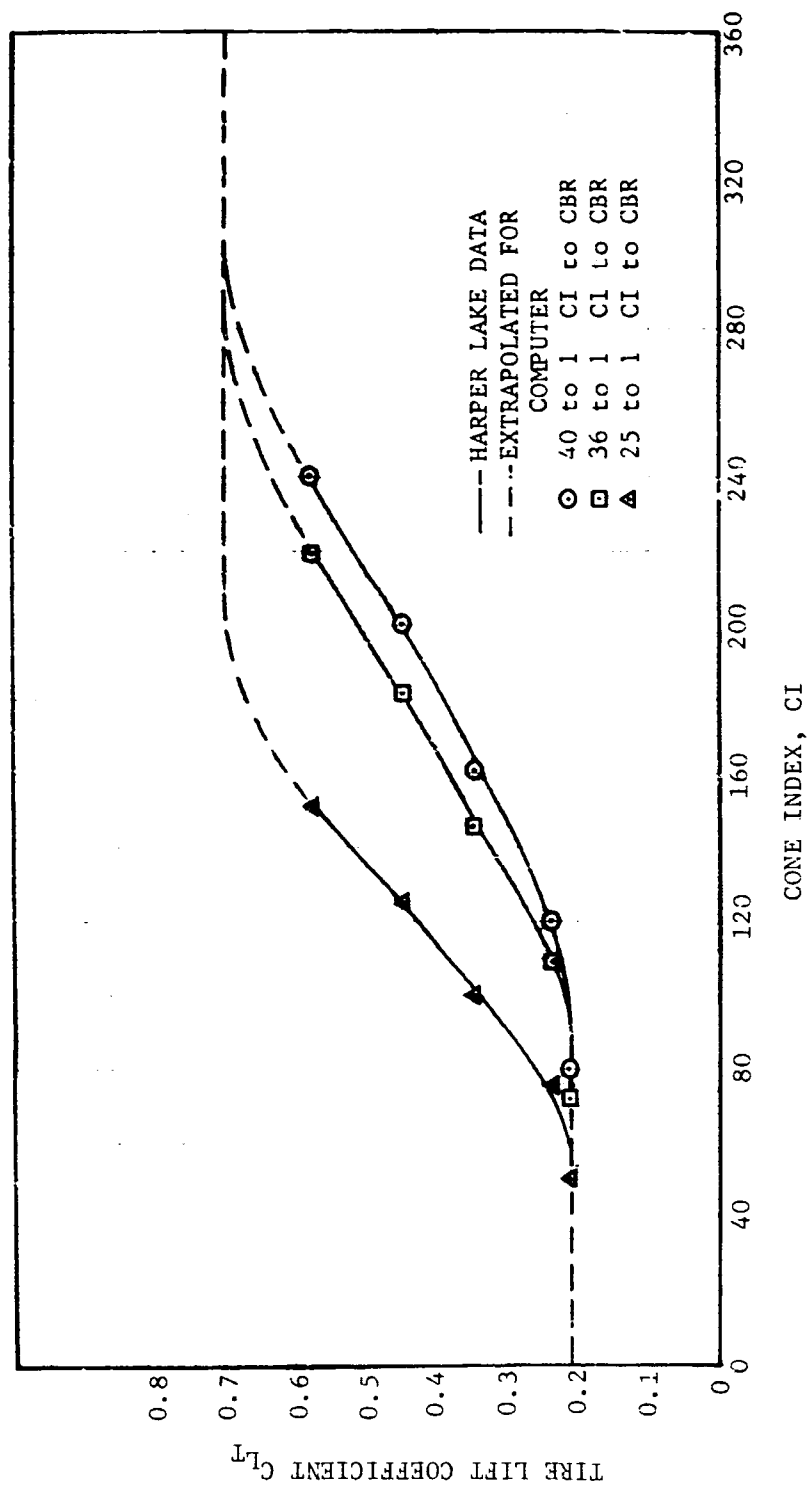


Figure 10 Experimental Tire Lift Coefficient

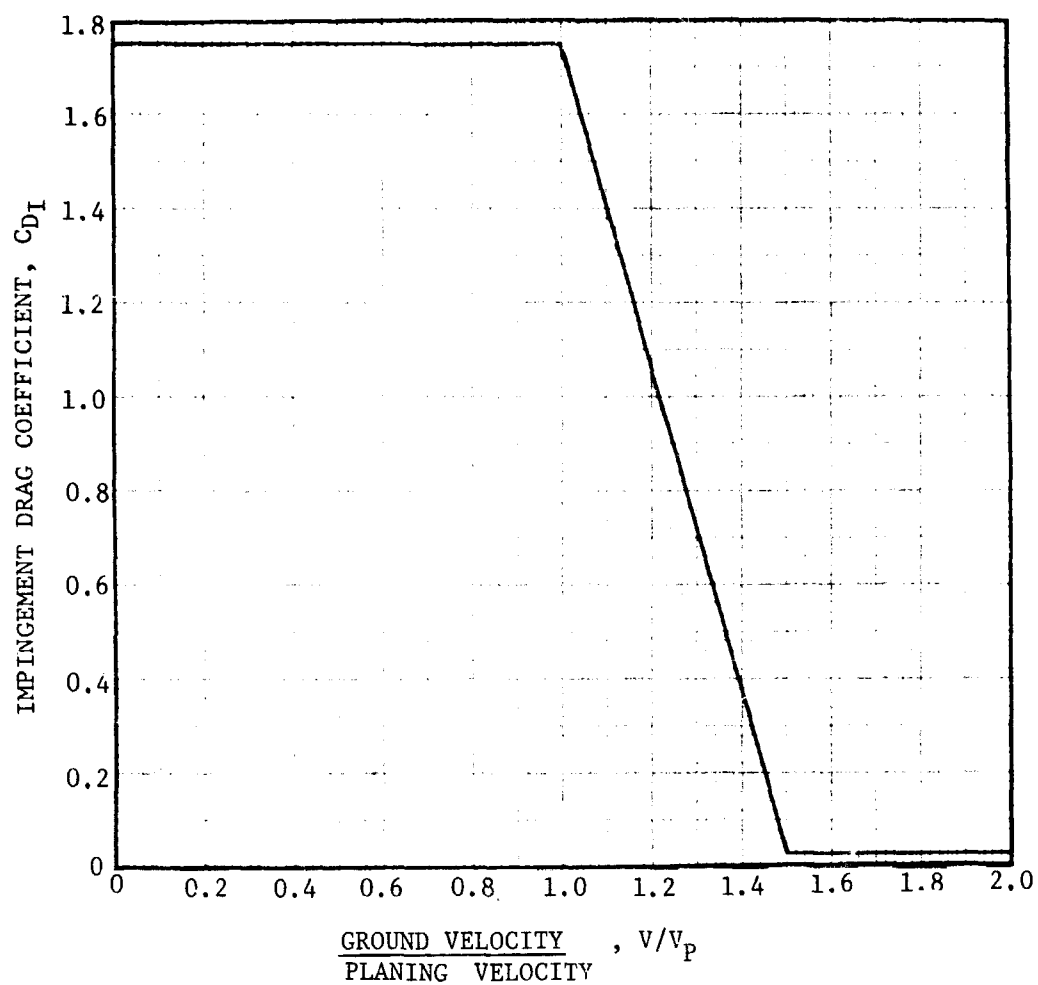


Figure 11 Impingement Drag Coefficient

$$F_{D_T} = (\mu_1^* + \mu_2^*) F_V + D_I (1 + TWF) \text{ for sand} \quad (20)$$

and

$$F_{D_T} = 2\mu^* F_V + D_I (1 + TWF) \text{ for clay}$$

$\mu^*, \mu_1^*, \mu_2^*$  = Rolling Resistance Coefficient from Equations 12, 13 and 14.

$F_V$  = Net downward vertical load.

$D_I$  = Impingement drag from Equation 15.

TWF = Tandem wheel factor for simplified rear wheel sinkage and drag, (0.4 for clay soil and 1.0 for sand soil).

Similarly, for a single or multiple side by side nose gear wheel,

$$F_{D_S} = (\mu^* F_V + D_I) N_W \text{ for clay} \quad (21)$$

or

$$F_{D_S} = (\mu_1^* F_V + D_I) N_W \text{ for sand.}$$

3. Formulation of Ground Acceleration Equation - Having defined the soil drag force, we can formulate the ground acceleration equation which when integrated will yield ground distance. Referring to Figure 1 and summing forces in a horizontal direction, we have

$$\Sigma F = ma$$

or solving for  $a$  and making substitutions for  $\Sigma F$

$$a = \frac{g}{W} \left[ T - D_a - (F_{D_N} + F_{D_M}) - W \cdot \phi \right] \quad (22)$$

where

$a$  = Aircraft ground acceleration (ft/sec<sup>2</sup>)

$g$  = Acceleration due to gravity (ft/sec<sup>2</sup>)

$W$  = Gross weight (lb)

$T$  = Total engine thrust (lb)

$D_a$  = Aerodynamic drag (lb) =  $C_D q A_W$

$F_{D_N}$  = Soil drag from nose tires (lb)

$F_{D_M}$  = Soil drag from main tires (lb)

$\phi$  = Runway slope (Rad)

Integration of equation 22 in a step-wise manner using a finite difference technique yields a time history of parameters such as soil drag, velocity, acceleration, sinkage and takeoff distance as a function of time.

Combining these results with equations of motion for the landing gear and aircraft structure will permit studies of dynamic response due to traversing soil airfields with non-level profiles. Limited studies of this type have shown a promising step toward a solution to soft field dynamic response prediction problems.

## SECTION III

### COMPUTER PROGRAM DESCRIPTION

The equations, theory and assumptions of Section II have been used to generate three computer programs which may be used to calculate soil sinkage, drag and takeoff performance on a clay or sandy soil. Three programs were generated so that the problem of landing gear drag could be considered when varying amounts of detailed information about the vehicle are known.

The simplest program, designated SOLDG, is designed to study soil drag when only the tire configuration and weight are known. The program assumes sufficient power to maintain a constant taxi velocity and zero aerodynamic lift and drag. The second program designated SOLDG2, also assumes a constant taxi velocity but includes a capability to consider aerodynamic lift and drag as well as a nose and main landing gear set with weight distribution controlled by cg location. Finally TAKOFF is a program which determines the takeoff distance required on soil and on pavement for an aircraft with all the variables of the first two programs but requires a precise description of thrust as a function of velocity. The program uses a 4-step Runge-Kutta integration routine for the distance computation. All the programs could have been incorporated into a single program, however, to avoid a number of confusing options, separate codes were used for each.

Complete documentation for use of the three programs with a sample problem for each is given in the appendices. Appendix A contains a complete listing of the three codes. Appendix B gives instructions for their use with sample problems to illustrate the set-up of the input data decks. Results of the sample problems are contained in Appendix C with a plotted comparison of results.

To assure that the programs were working properly, the same simulation which was made by Boeing is reproduced as closely as possible. This correlation as well as estimates of the performance capability of the C-141 and C-5 aircraft are presented in the next sections.

## SECTION IV

### CORRELATION OF COMPUTER PROGRAM RESULTS USING THE BOEING 367-80 AIRCRAFT

1. Discussion - To assure that the computer programs were accurately coded, a performance correlation was made with results obtained by Boeing using the 367-80 aircraft as the analytical vehicle. Comparisons were made of paved takeoff performance, soil takeoff performance and velocity histories of soil drag ratio and wheel sinkage.

2. Results - Figures 12, 13 and 14 show paved surface performance of the 367-80 operating on Boeing Field. The analytical data agrees well with experimental results and would probably come even closer had the Boeing Field runway slope been accounted for. Figure 15 shows analytical and experimental drag ratio comparisons. Drag ratio is simply the total soil drag divided by the total vertical load (weight minus lift). The difference between experimental and analytical results in this figure is quite sizable at some speeds. Discussions with Boeing, however, indicate that the experimental data were quite scattered for this test and that under the circumstances, the analytical results are reasonable approximations. Figures 16 and 17 are, respectively, analytical sinkage history and a velocity-distance comparison for the runs of Figure 15. Figure 18 shows a drag ratio history similar to that of Figure 15 except for a sandy soil. Figures 19 and 20 show the percentage increase in takeoff distance as a function of soil strength. Figure 19 shows a considerable variation between the Boeing results and the FDDS correlation. There are a number of reasons for this variation, but the greatest cause is probably differences in the data used for the analytical vehicle. Slight variations in tire deflection curves, center of gravity location and other similar parameters could very easily cause the magnitude of the variations shown. The data for the 367-80 vehicle used in this correlation are presented in Appendix D. The 367-80 correlation study has given sufficient confidence in the method and the computer programs to warrant making a study of the C-141 and C-5 vehicles which will be required to operate on substandard landing sites. Assessment of the performance capability of the C-141 and C-5 aircraft are covered in detail in the next two sections.

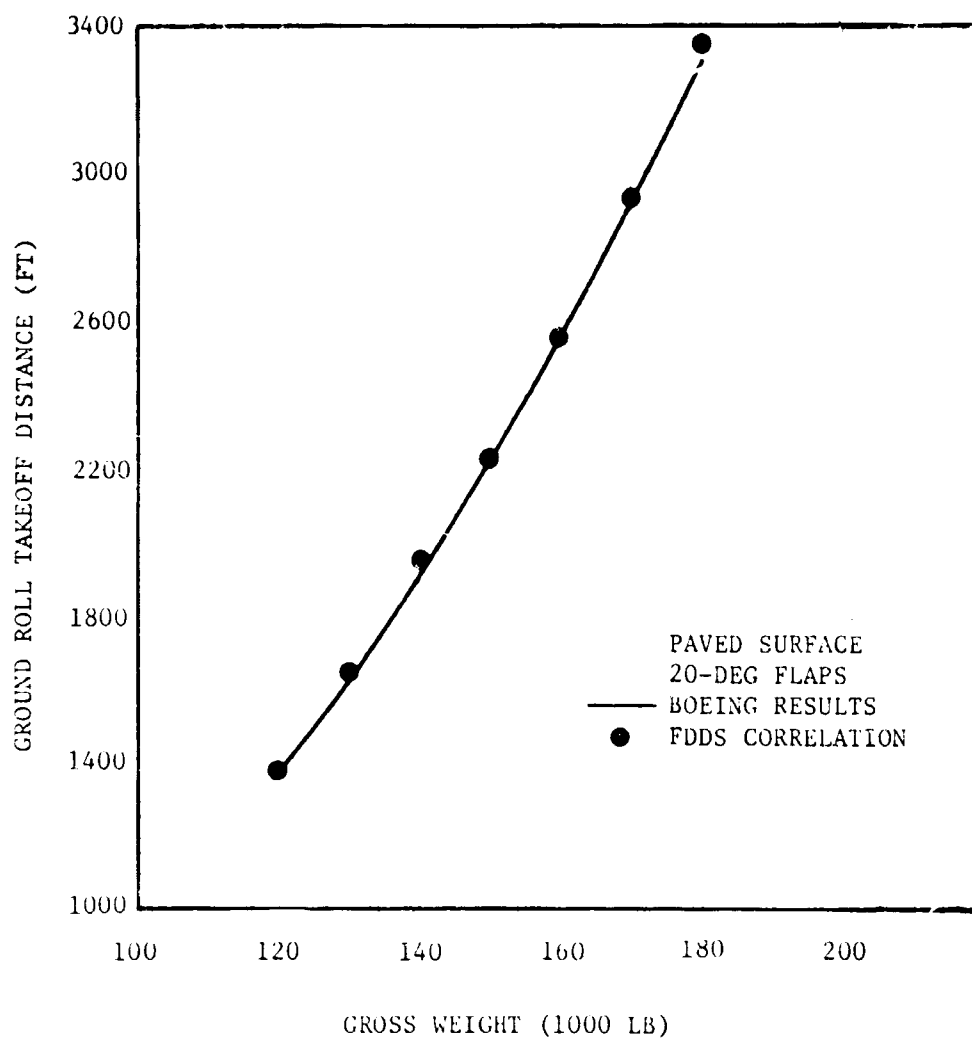


Figure 12 Paved Surface Ground Roll Takeoff Distance as a Function of Gross Weight, 367-80.

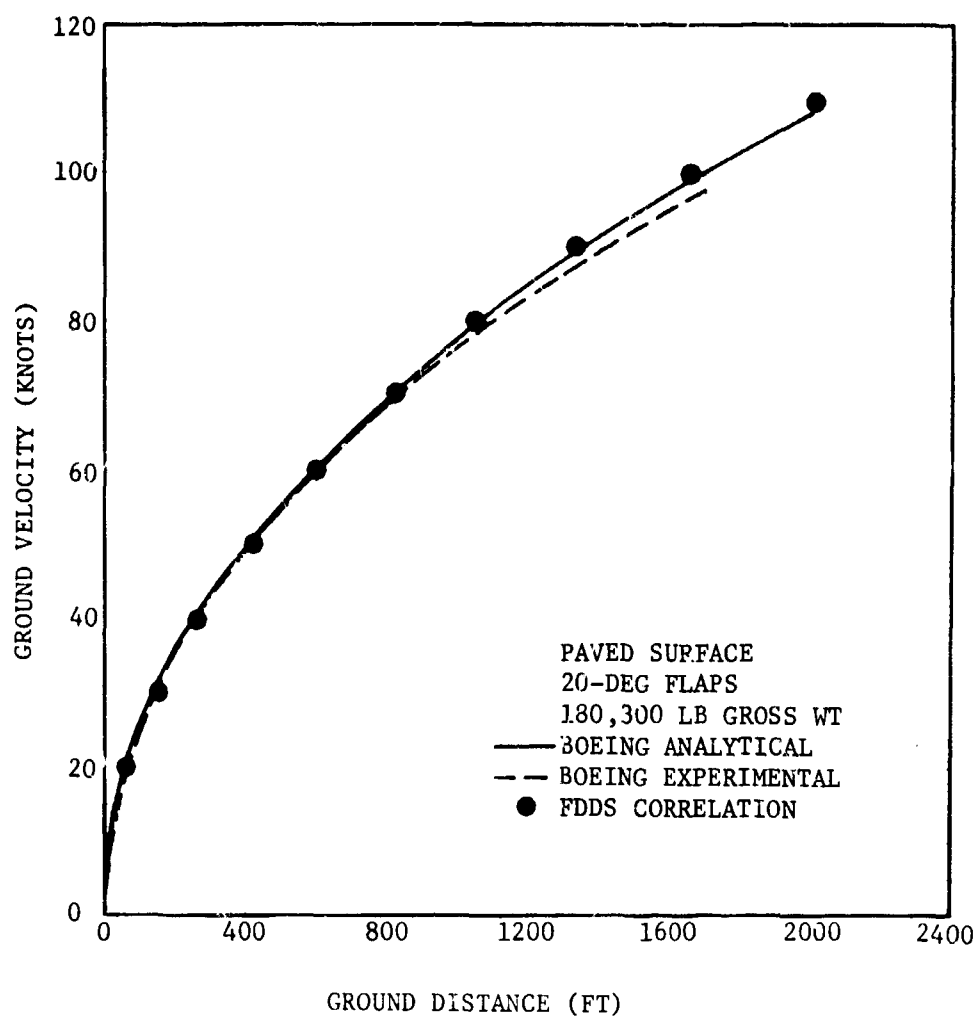


Figure 13 Paved Surface Ground Velocity as a Function of Ground Distance, 367-80, 180,300 lb. Gross Weight

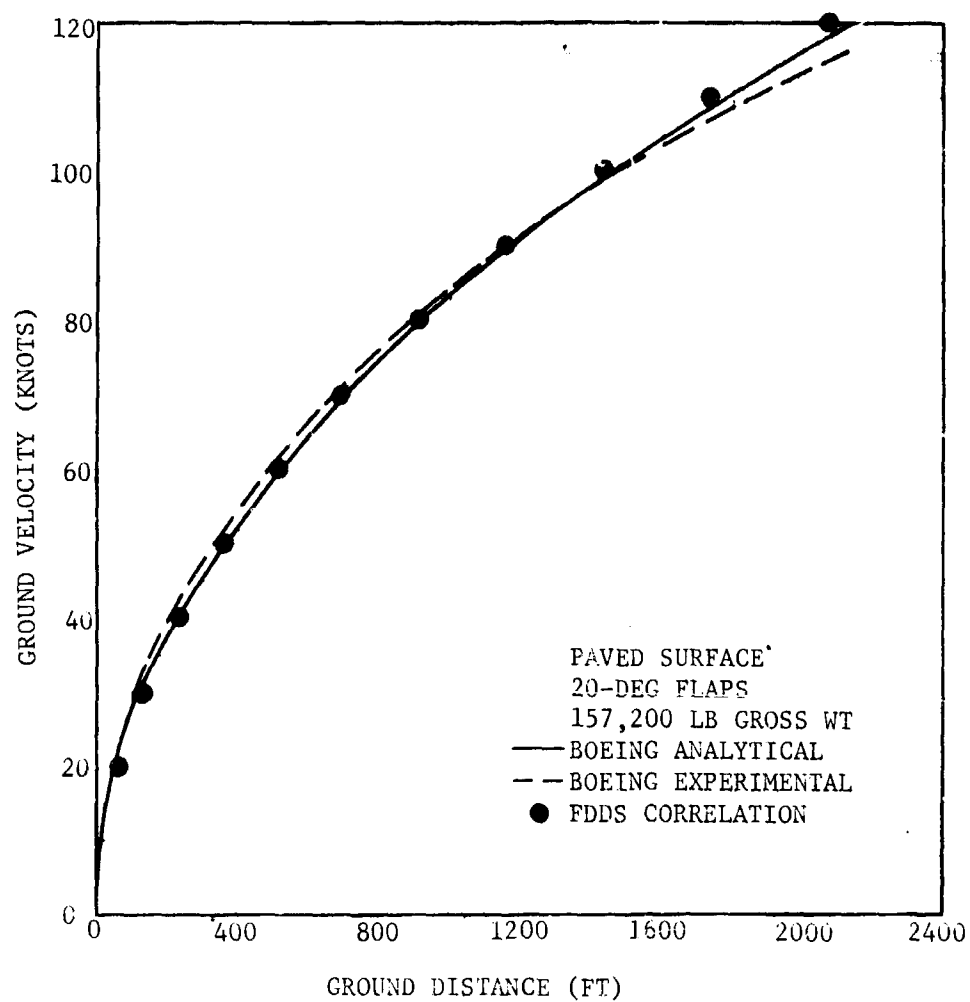


Figure 14 Paved Surface Ground Velocity as a Function of Ground Distance, 367-80, 157,200 lb. Gross Weight

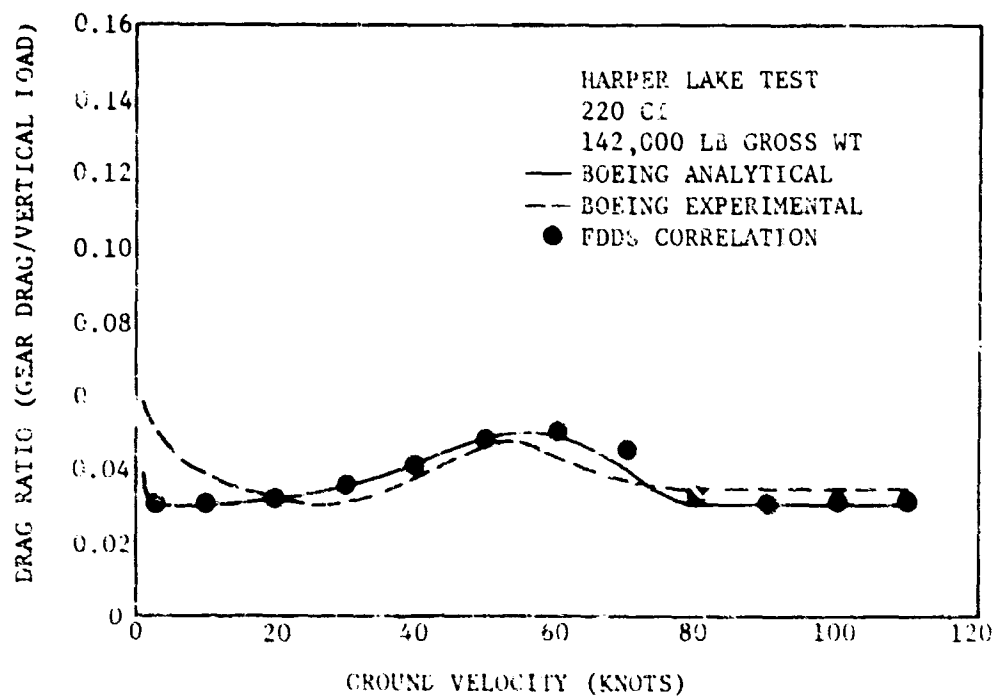
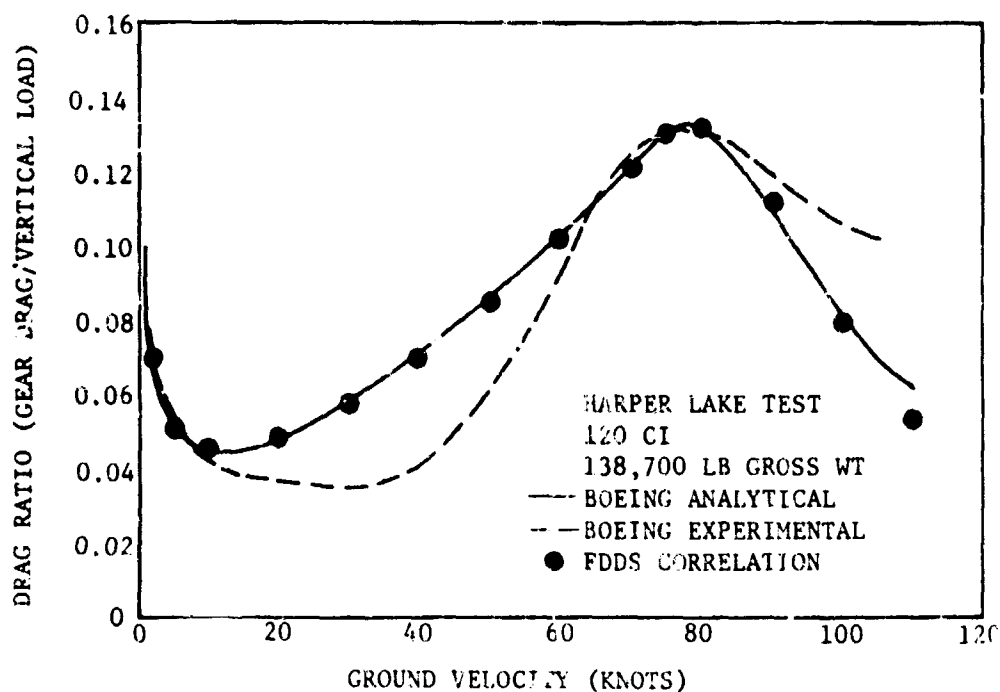


Figure 15 Drag Ratio as a Function of Ground Velocity for 367-80 at 138,700 and 142,000 lb. Gross Weight

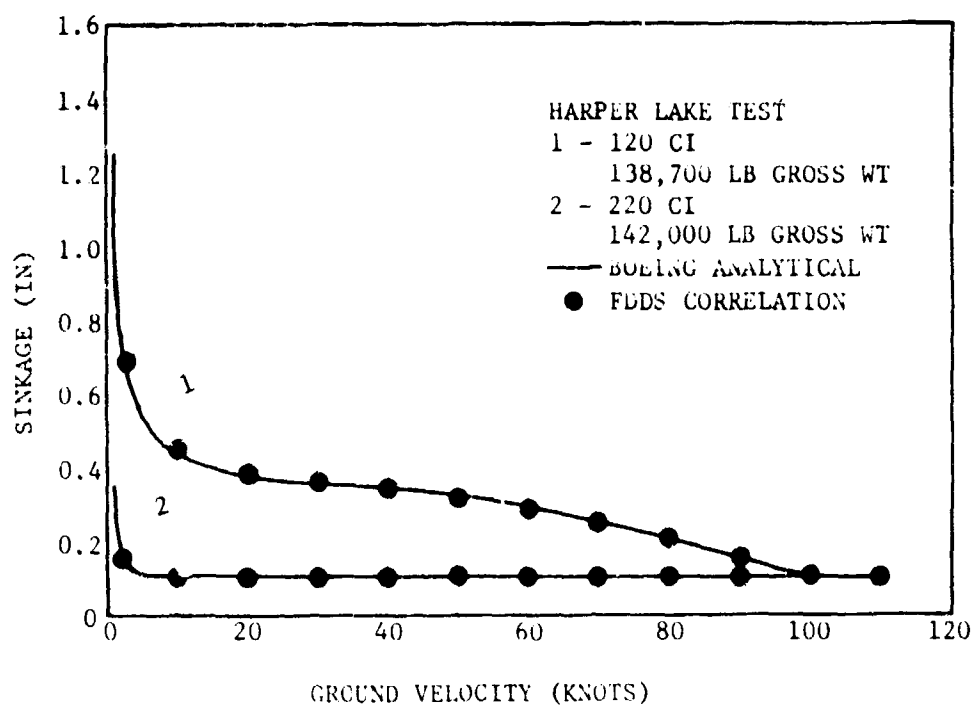


Figure 16 Soil Sinkage as a Function of Ground Velocity for 367-80  
 at 138,700 and 142,000 LB Gross Weight

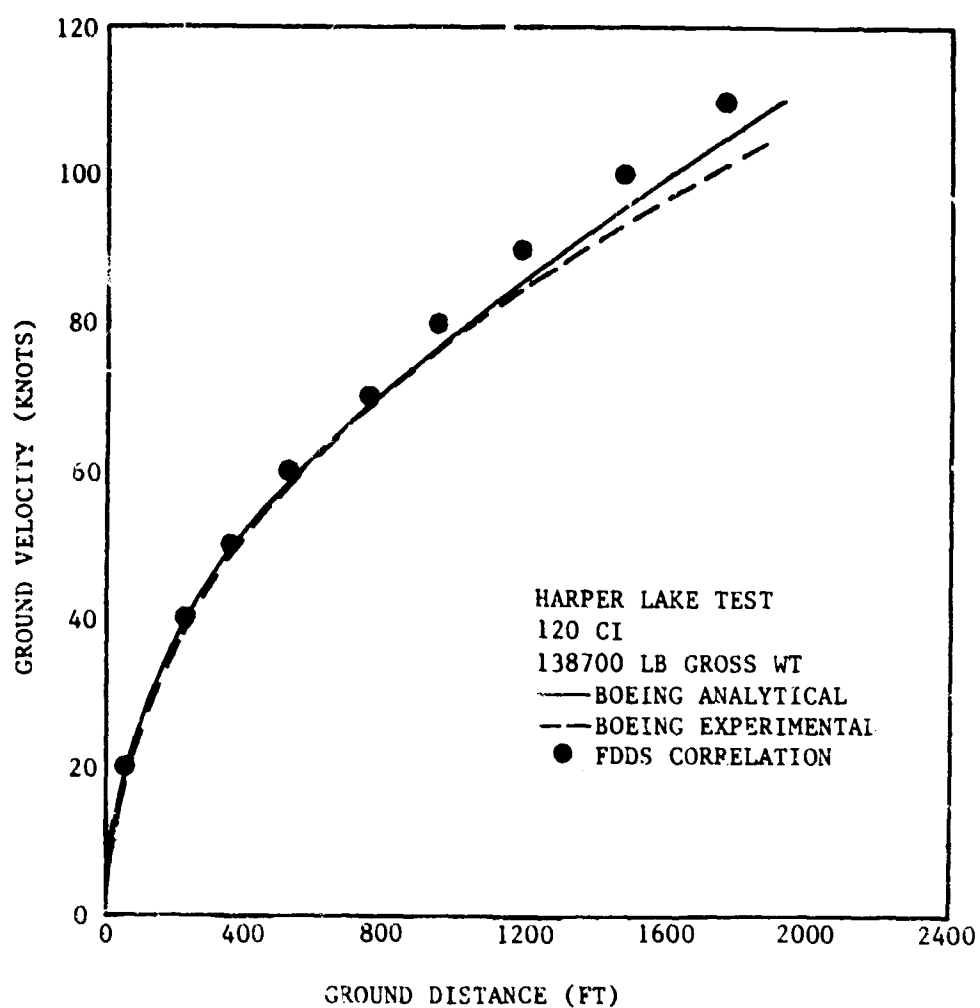


Figure 17 Ground Velocity as a Function of Ground Distance for 367-80 at 138,700 lb. Gross Weight.

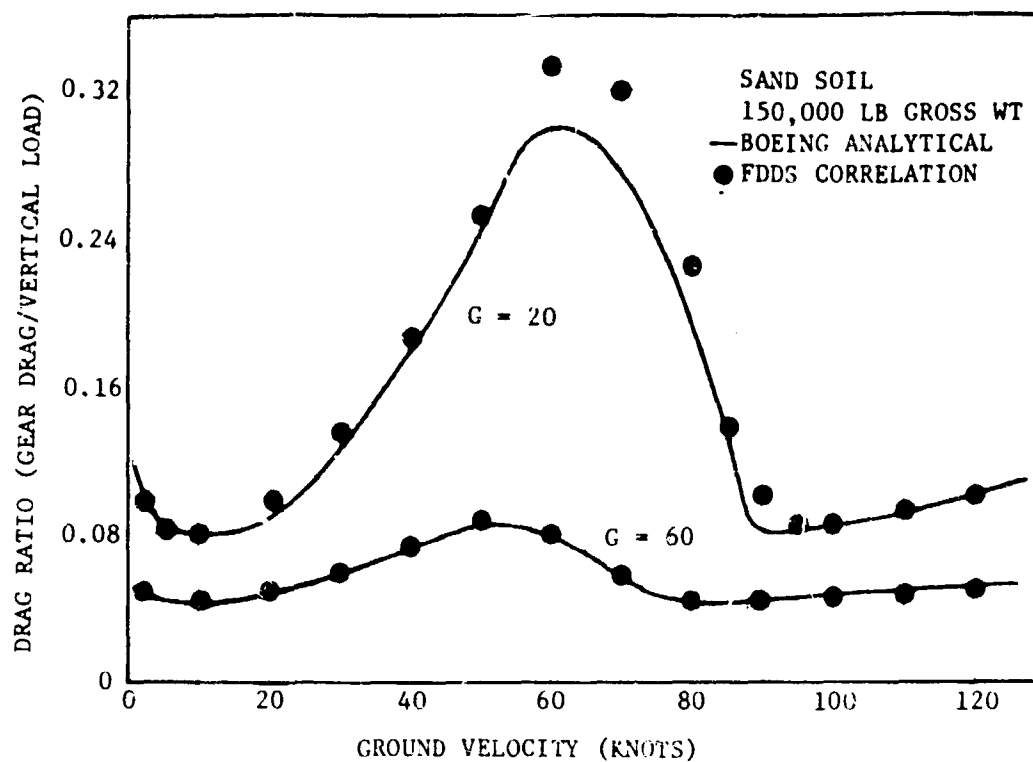


Figure 18 Drag Ratio as a Function of Ground Velocity for 367-80 at 150,000 lb. Gross Weight

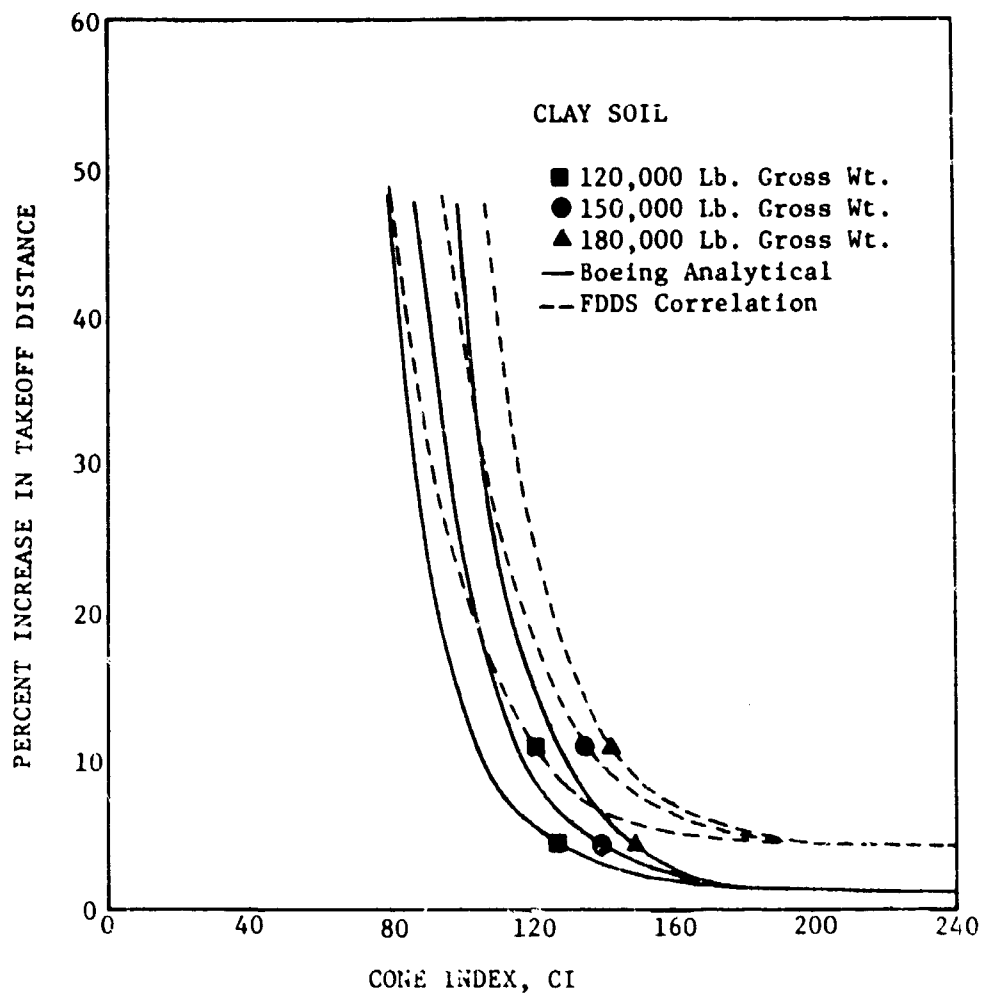


Figure 19 Percent Increase in Takeoff Distance Over Paved Surface

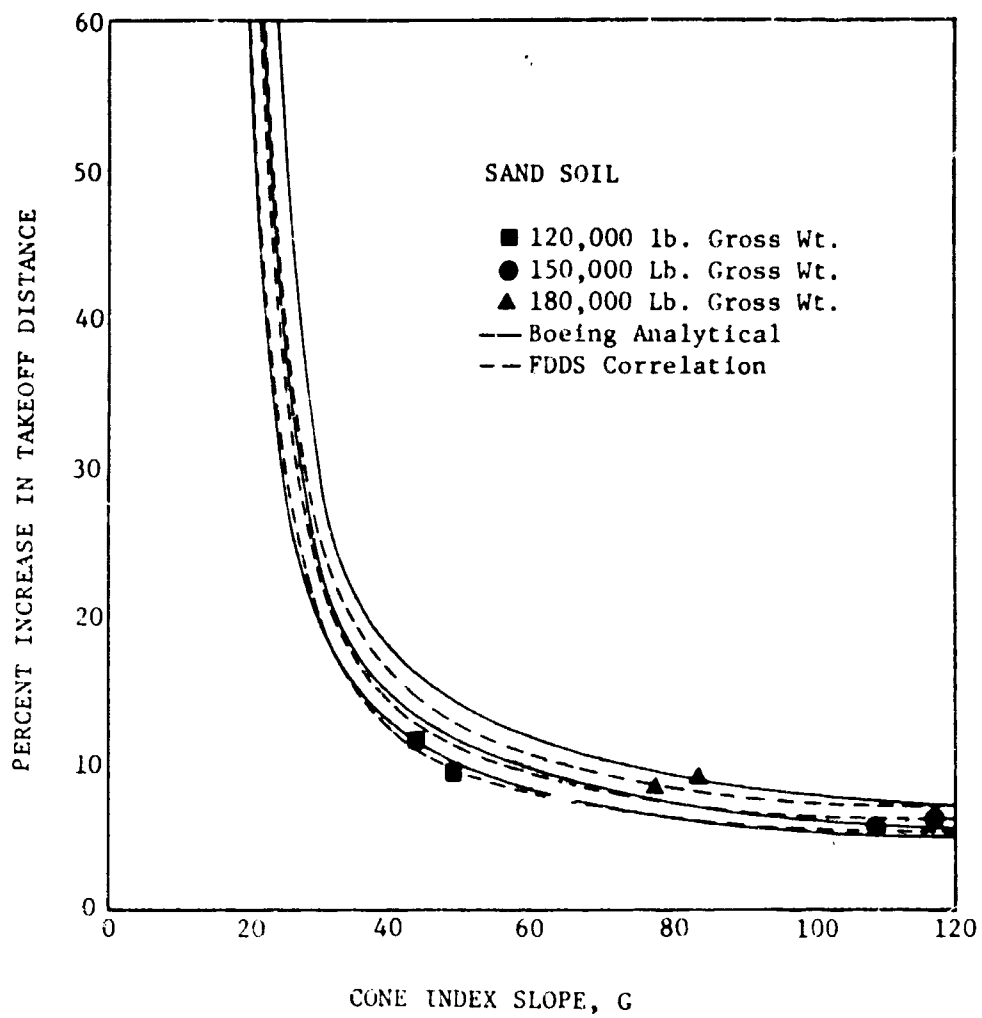


Figure 20 Percent Increase in Takeoff Distance Over Paved Surface

## SECTION V

### PERFORMANCE OF C-141 AIRCRAFT OPERATING ON CLAY AND SAND AIRFIELDS

1. Discussion - Since the C-141 aircraft is one of the most widely used cargo and troop transport vehicles presently being used by the Air Force, it follows that questions continue to arise concerning its ability to operate from landing fields which are not paved. The results presented in the next paragraph attempt to make an assessment of the drag loads experienced and the change in takeoff performance which will result from operation on clay and sand type fields. No attempt was made to determine the number of times a particular takeoff run could be made on a single soil strength before the surface strength characteristics deteriorated to an unacceptable level. This study is concerned only with obtaining a minimum soil strength for a particular configuration. The basic data used in the computer program is given in Appendix E.

2. Results - As in the previous section, the results of operating the C-141 aircraft on clay and sand soil is compared to paved surface operation, and therefore, paved surface takeoff performance is presented first (Figure 21). Exact duplication of the takeoff distance presented in the C-141 handbook (Reference 5) could not be made since a more sophisticated computer program was used for the handbook data. The handbook results are calculated assuming that a rotation velocity and a takeoff velocity must be reached during the ground roll. This standard technique requires a time history of angle of attack and results in a varying lift and drag coefficient between the rotation speed and liftoff speed. The present program assumed that no angle of attack change occurs until liftoff speed is reached. As a result, most of the program results show a shorter paved surface ground distance.

To obtain a representative sample of C-141 soil performance, calculations were made for three gross weights, three soil strengths for clay, three soil strengths for sand and two tire pressures. Table 1 lists the figure number for each configuration analyzed. The figures are arranged in groups of three. The first of each group is the ratio of soil drag and vertical load as a function of ground speed, the second is main gear sinkage for the same condition and the third of the series is ground velocity as a function of ground distance. At the end of each three gross weight series is a curve of percent increase in takeoff distance over paved surface as a function of soil strengths. Figures 34, 44, 54 and 64 are the four such curves produced in this study. Figure 34 and Figure 44 may be compared to show the effects of a change in tire pressure on clay and Figures 54 and 64 for the same results on sand. Comparison of Figures 34 and 54 will give the results of changing from clay to sand soil for the same condition. Although the present study was limited, it appears that a reasonably good off-runway capability exists, particularly in the higher cone index strengths investigated.

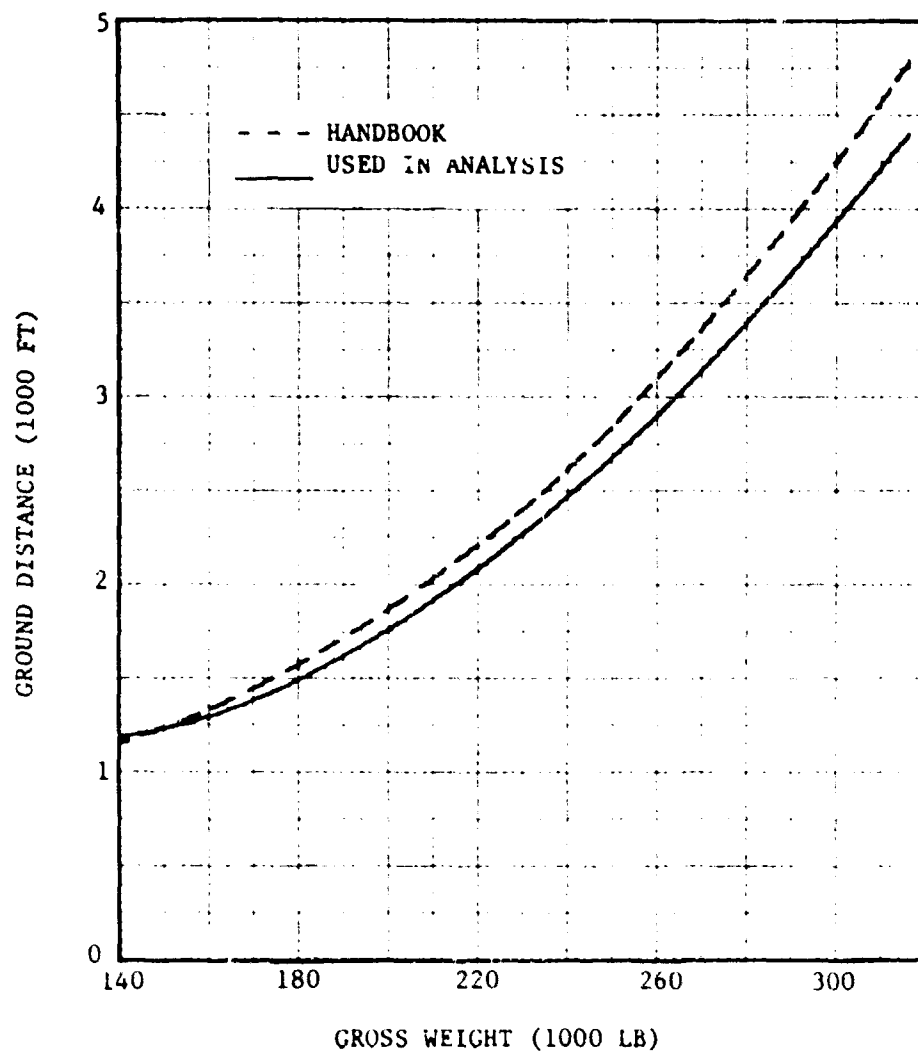


Figure 21 C-141 Paved Surface Takeoff Ground Roll as a Function of Gross Weight

TABLE 1  
C-141 CONFIGURATION SUMMARY

Gross Weight	Surface Type	Surface Strength (CI for Clay) ( G for Sand)	Tire Pressure	Figure Nr.
160,000	Paved	-	-	22
220,000	Paved	-	-	23
280,000	Paved	-	-	24
160,000	Clay	150,200,300	100 Psi	25
160,000	Clay	150,200,300	100 Psi	26
160,000	Clay	150,200,300	100 Psi	27
220,000	Clay	220,260,325	100 Psi	28
220,000	Clay	220,260,325	100 Psi	29
220,000	Clay	220,260,325	100 Psi	30
280,000	Clay	275,300,350	100 Psi	31
280,000	Clay	275,300,350	100 Psi	32
280,000	Clay	275,300,350	100 Psi	33
160,000	Clay	150,200,300	130 Psi	35
160,000	Clay	150,200,300	130 Psi	36
160,000	Clay	150,200,300	130 Psi	37
220,000	Clay	220,260,325	130 Psi	38
220,000	Clay	220,260,325	130 Psi	39
220,000	Clay	220,260,325	130 Psi	40
280,000	Clay	275,300,350	130 Psi	41
280,000	Clay	275,300,350	130 Psi	42
280,000	Clay	275,300,350	130 Psi	43
160,000	Sand	45,65,100	100 Psi	45
160,000	Sand	45,65,100	100 Psi	46
160,000	Sand	45,65,100	100 Psi	47
220,000	Sand	60,80,100	100 Psi	48
220,000	Sand	60,80,100	100 Psi	49
220,000	Sand	60,80,100	100 Psi	50
280,000	Sand	70,100,125	100 Psi	51
280,000	Sand	70,100,125	100 Psi	52
280,000	Sand	70,100,125	100 Psi	53
160,000	Sand	45,65,100	130 Psi	55
160,000	Sand	45,65,100	130 Psi	56
160,000	Sand	45,65,100	130 Psi	57
220,000	Sand	60,80,100	130 Psi	58
220,000	Sand	60,80,100	130 Psi	59
220,000	Sand	60,80,100	130 Psi	60
280,000	Sand	70,100,125	130 Psi	61
280,000	Sand	70,100,125	130 Psi	62
280,000	Sand	70,100,125	130 Psi	63

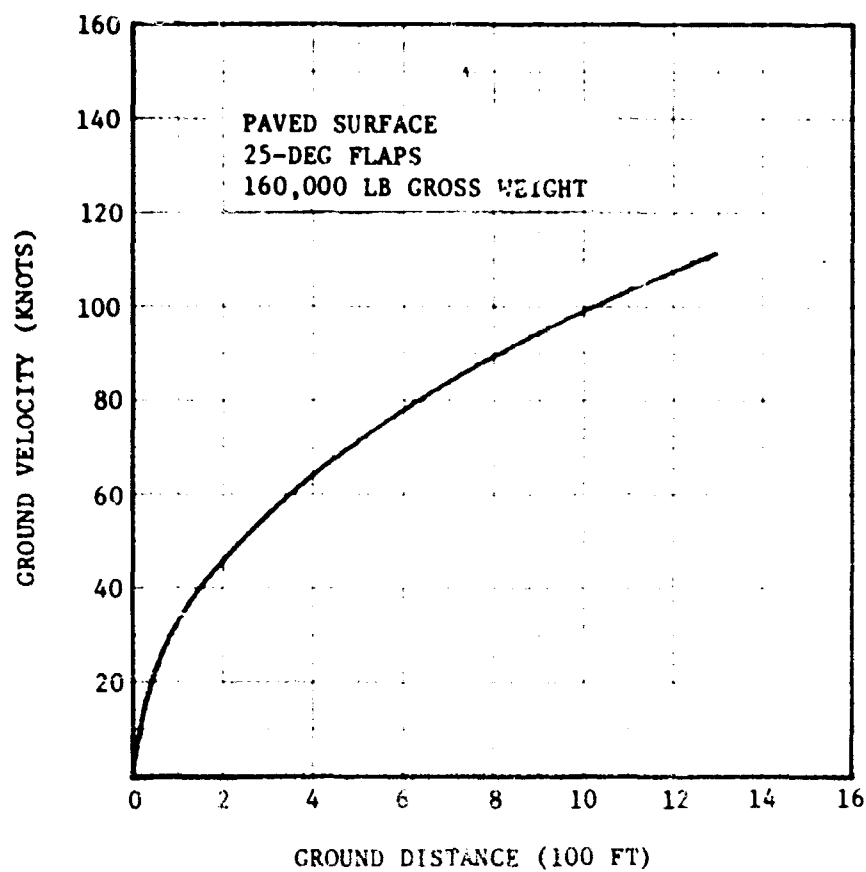


Figure 22. Airplane Velocity as a Function of Ground Distance, C-141, 160,000 lb. Gross Weight

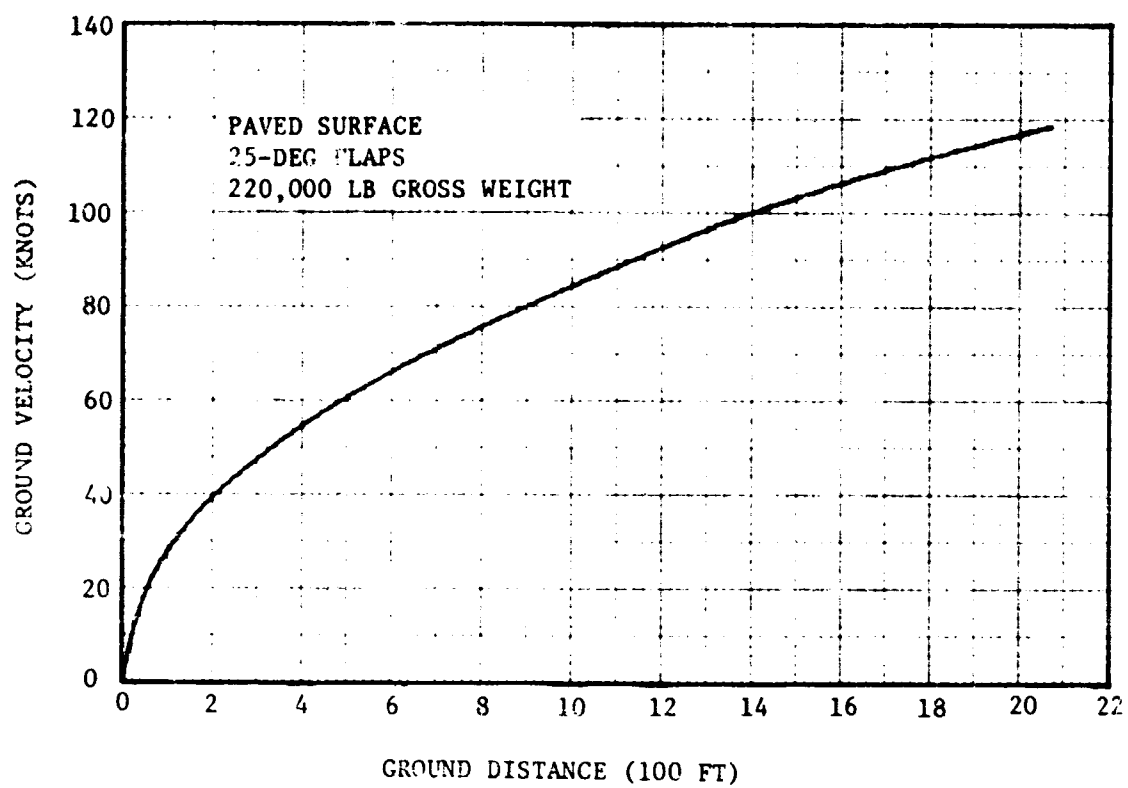


Figure 23. Airplane Velocity as a Function of Ground Distance, C-141, 220,000 lb, Gross Weight

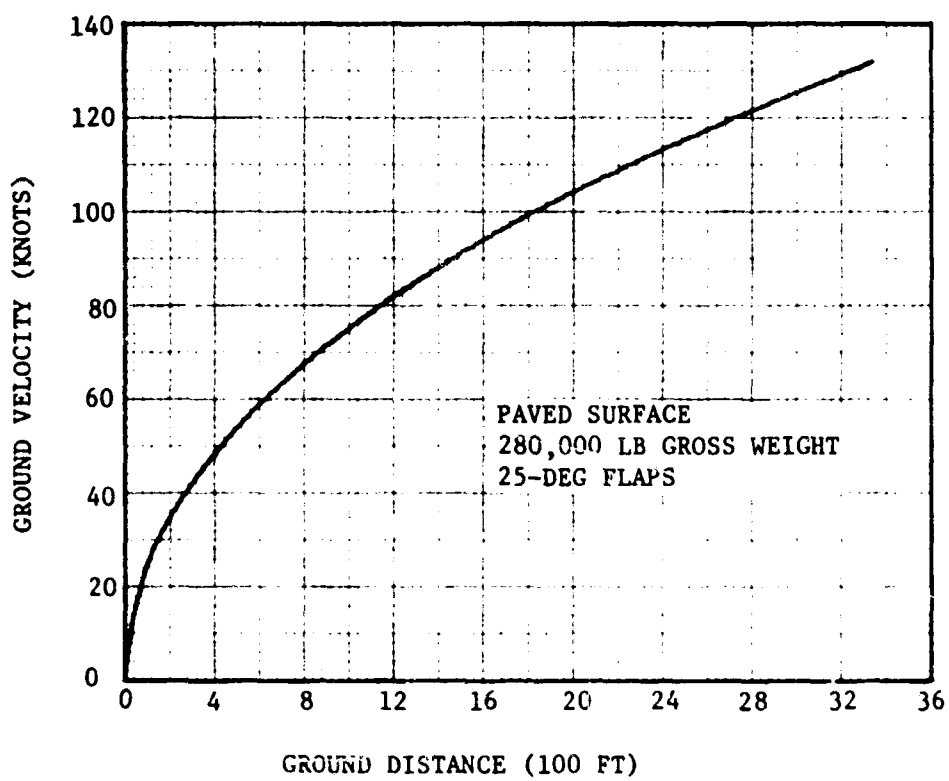


Figure 24. Airplane Velocity as a Function of Ground Distance, C-141, 280,000 lb. Gross Weight

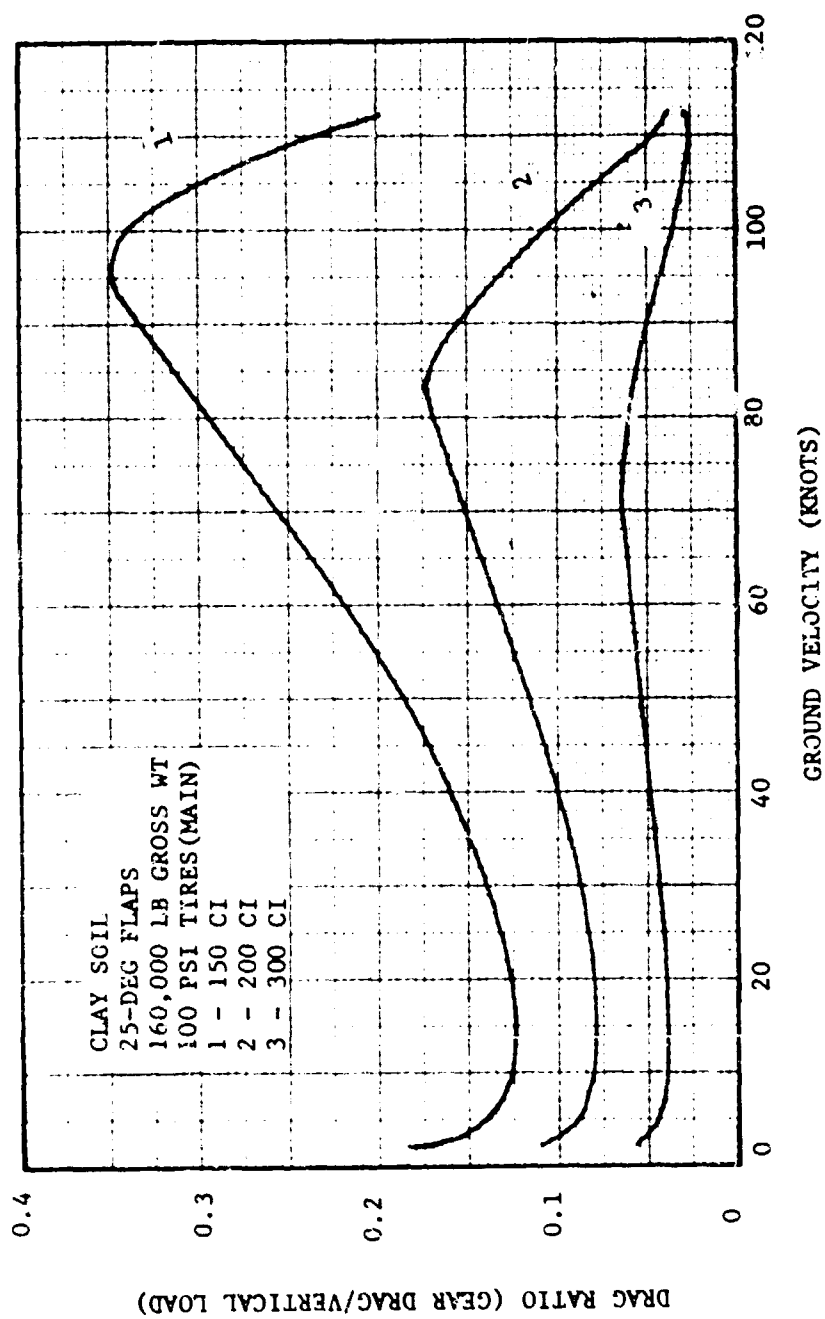


Figure 25 Drag Ratio as a Function of Ground Velocity for C-141 at 160,000 lb. Gross Weight

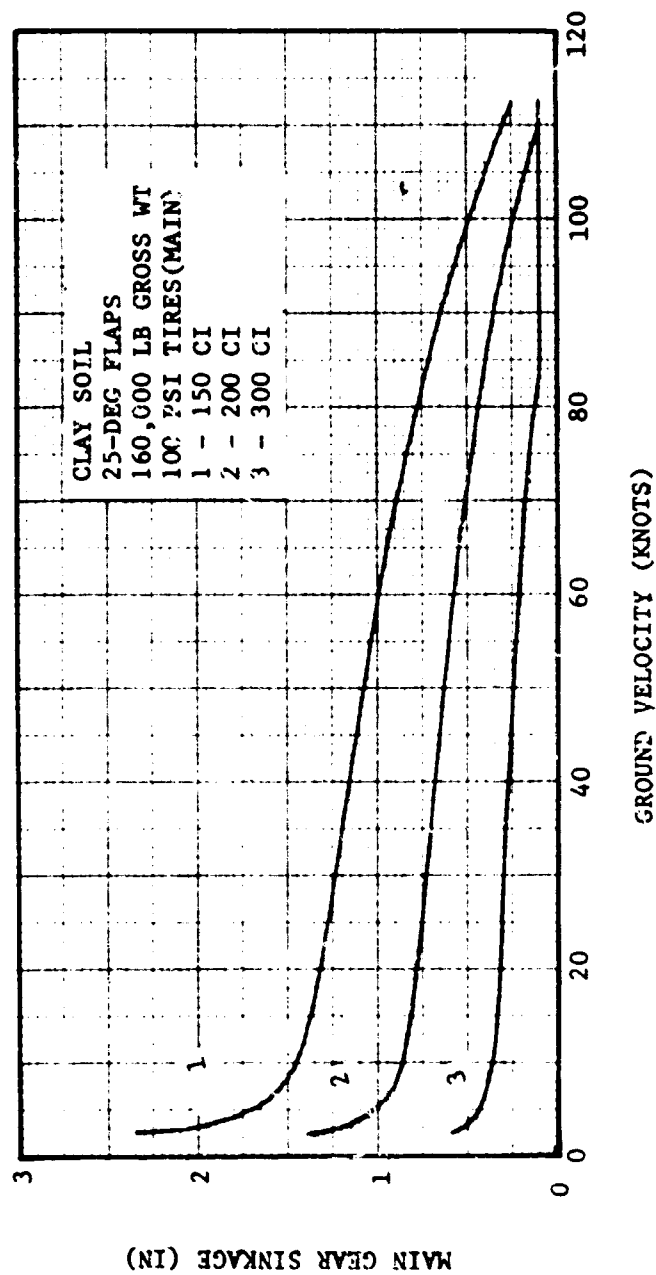


Figure 26 Soil Sinkage as a Function of Ground Velocity  
for C-141 at 160,000 Lb. Gross Weight

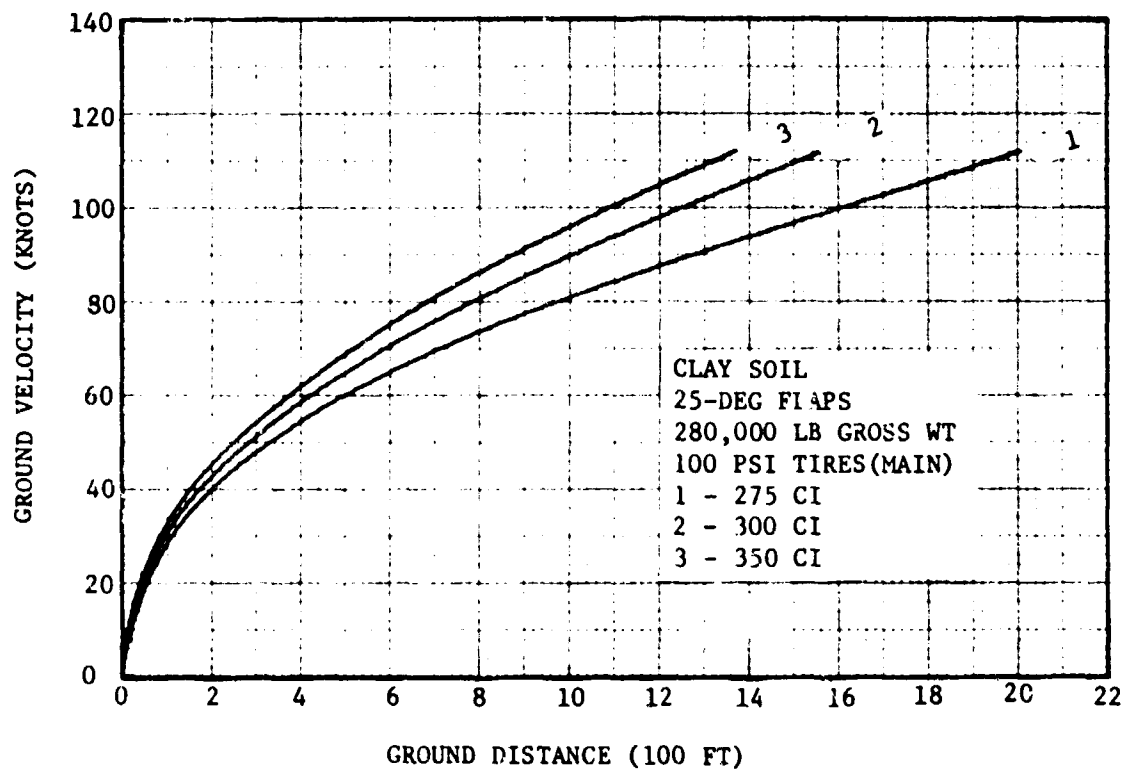


Figure 27. Airplane Velocity as a Function of Ground Distance for C-141 at 160,000 lb. Gross Weight

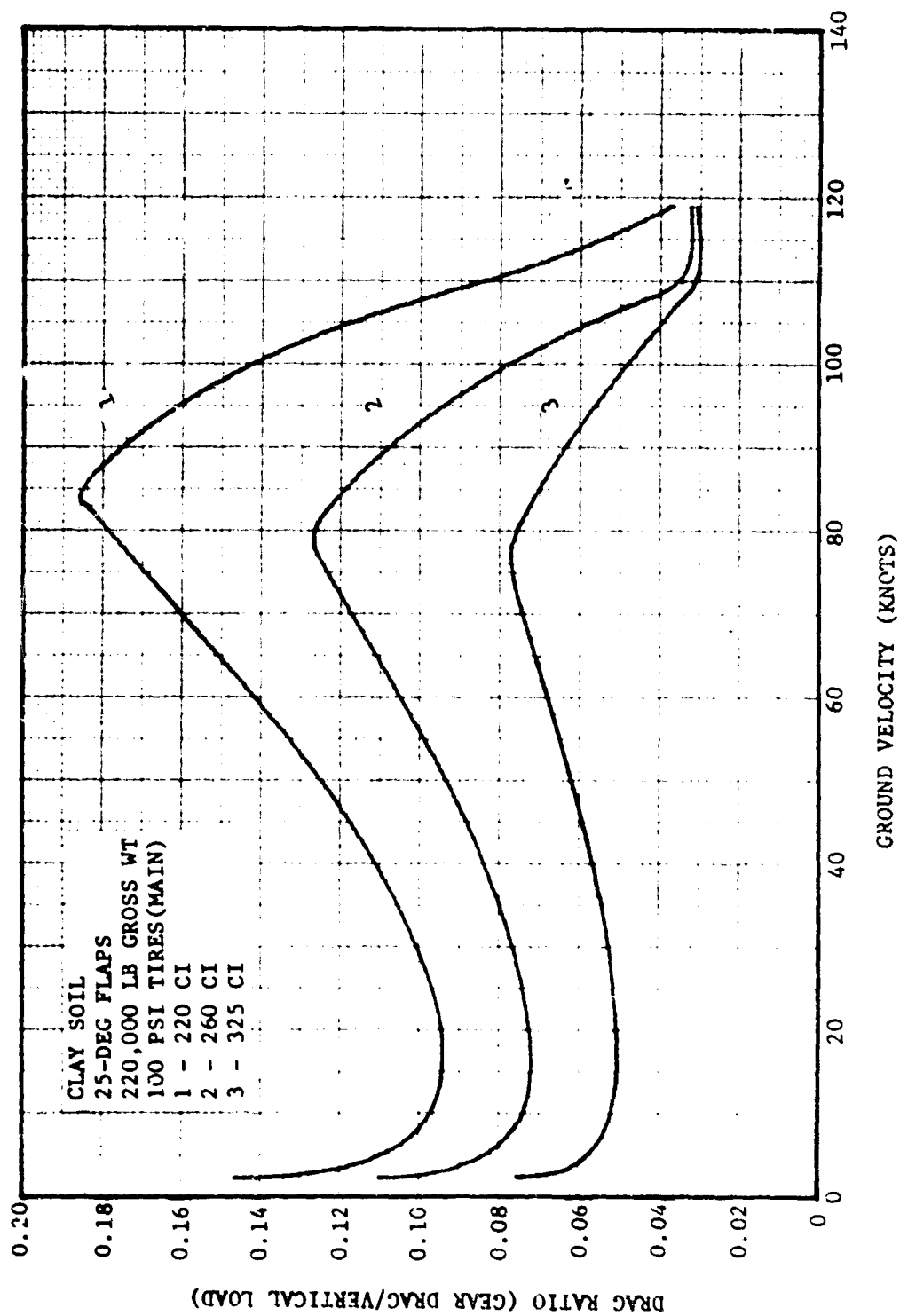


Figure 28 Drag Ratio as a Function of Ground Velocity for  
C-1,1 at 220,000 Lb. Gross Weight

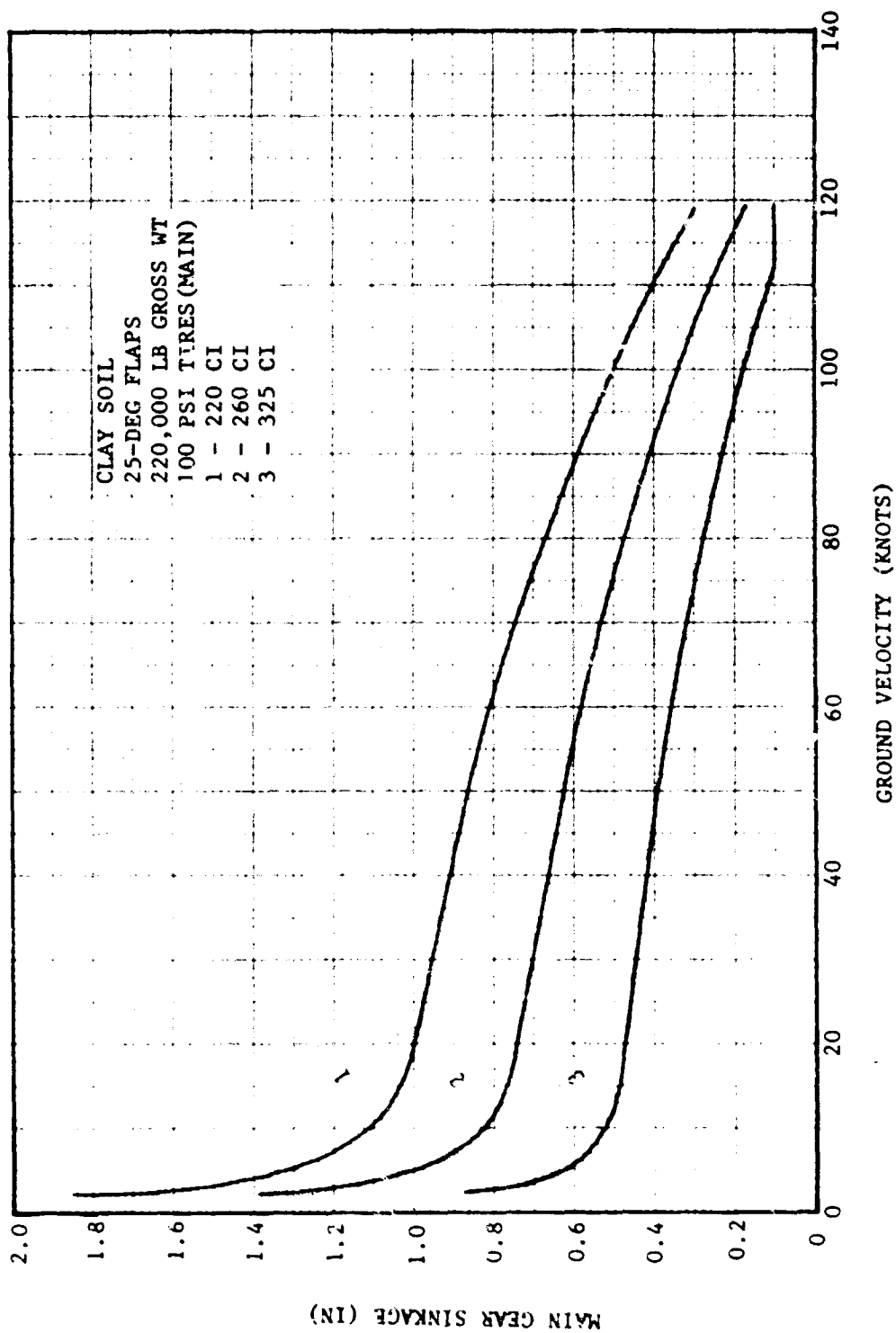


Figure 29 Soil Sinkage as a Function of Ground Velocity for C-141 at 220,000 Lb. Gross Weight

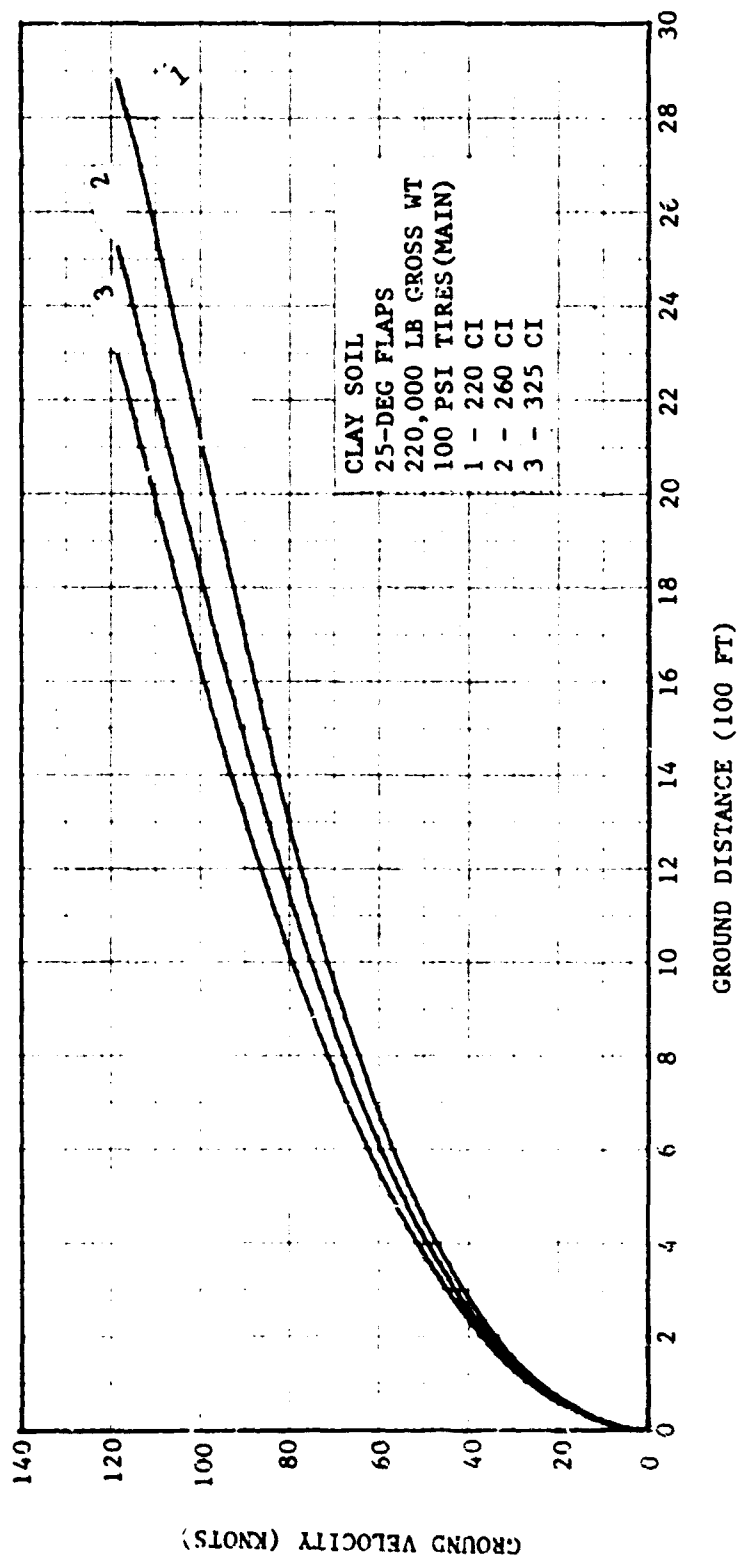


Figure 30. Airplane Velocity as a Function of Ground Distance  
for C-141 at 220,000 lb, Gross Weight.

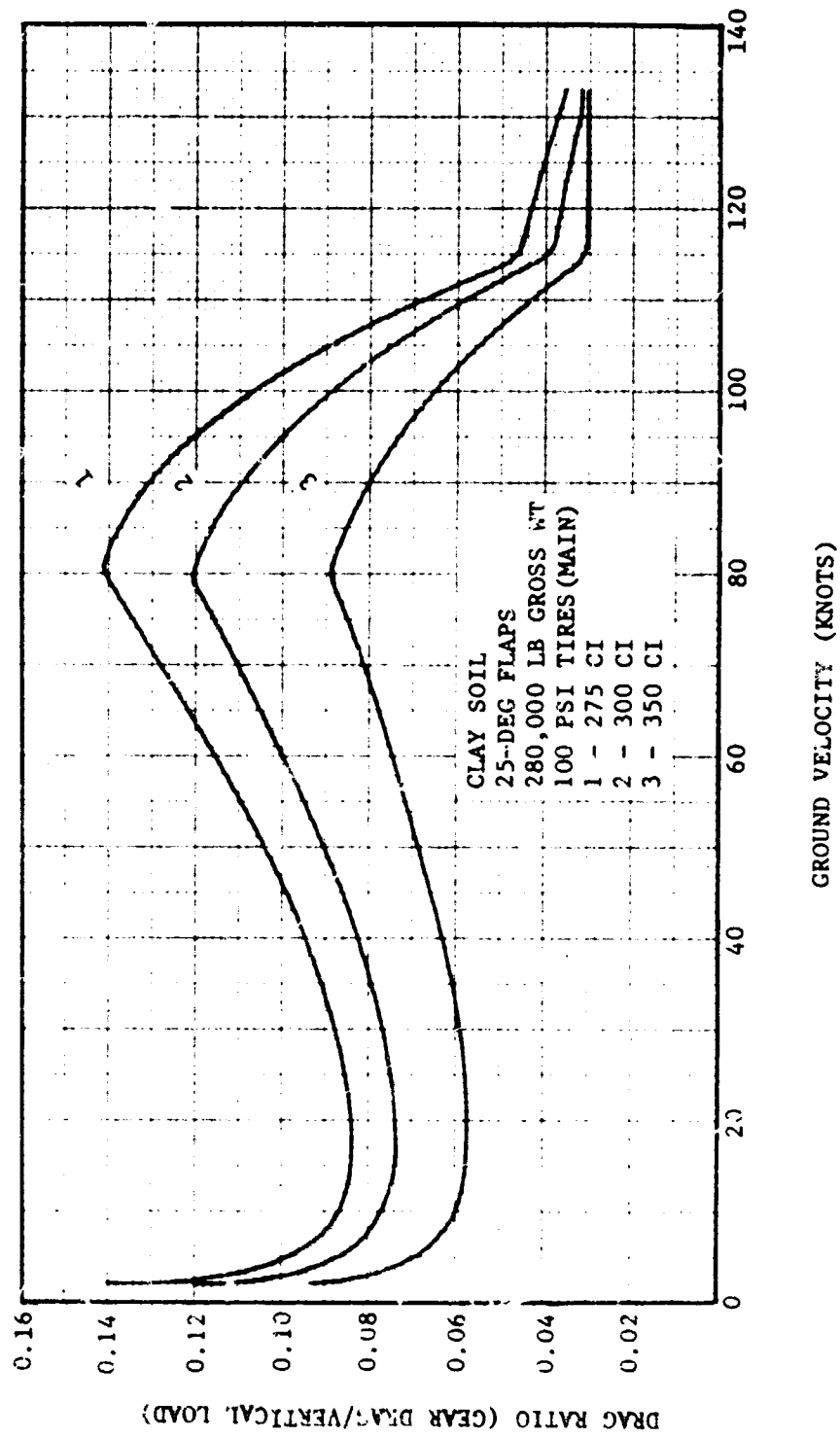


Figure 31 Drag Ratio as a Function of Ground Velocity for C-141 at 280,000 Lb. Gross Weight

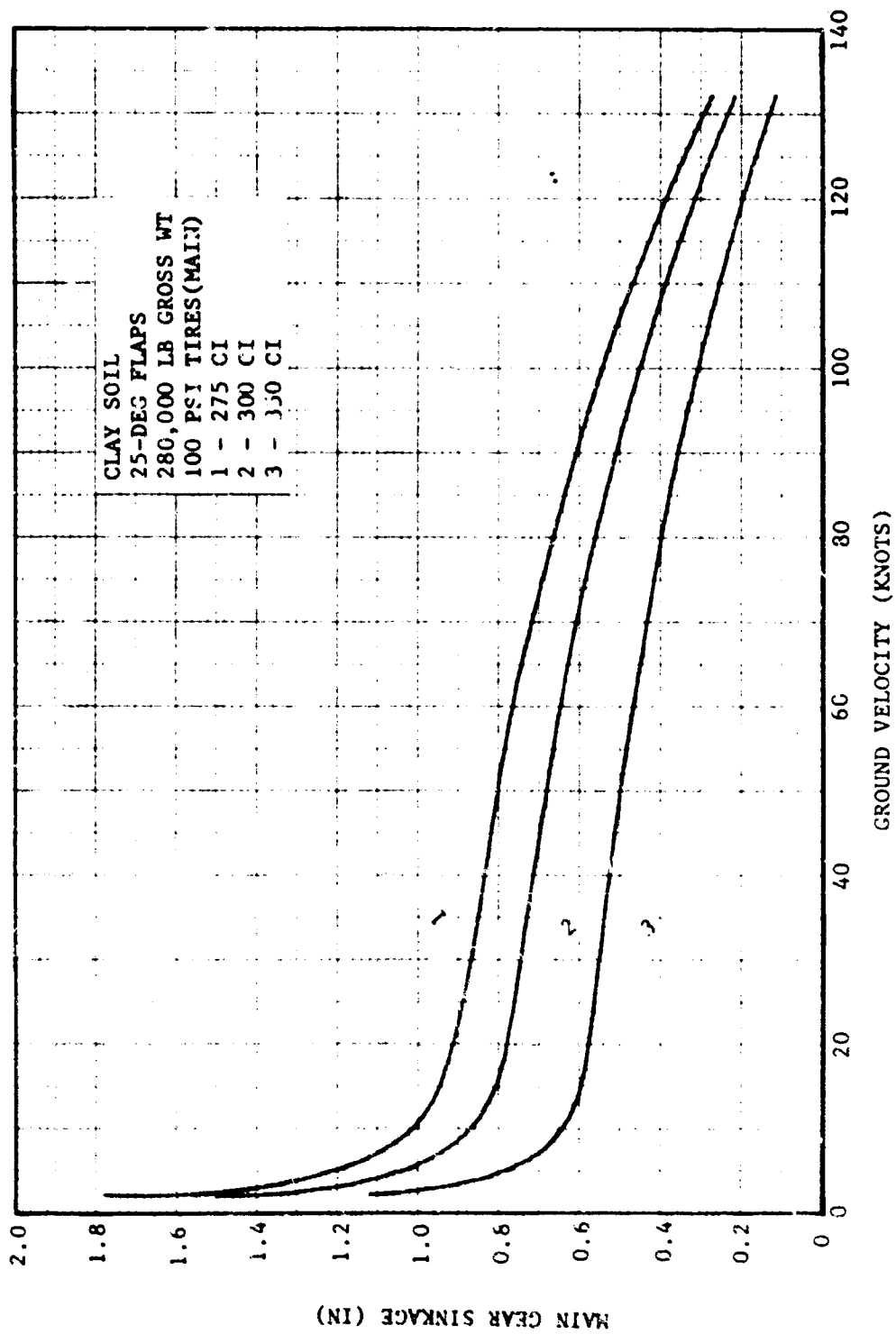


Figure 32 Soil Sinkage as a Function of Ground Velocity  
for C-141 at 280,000 Lb. Gross Weight

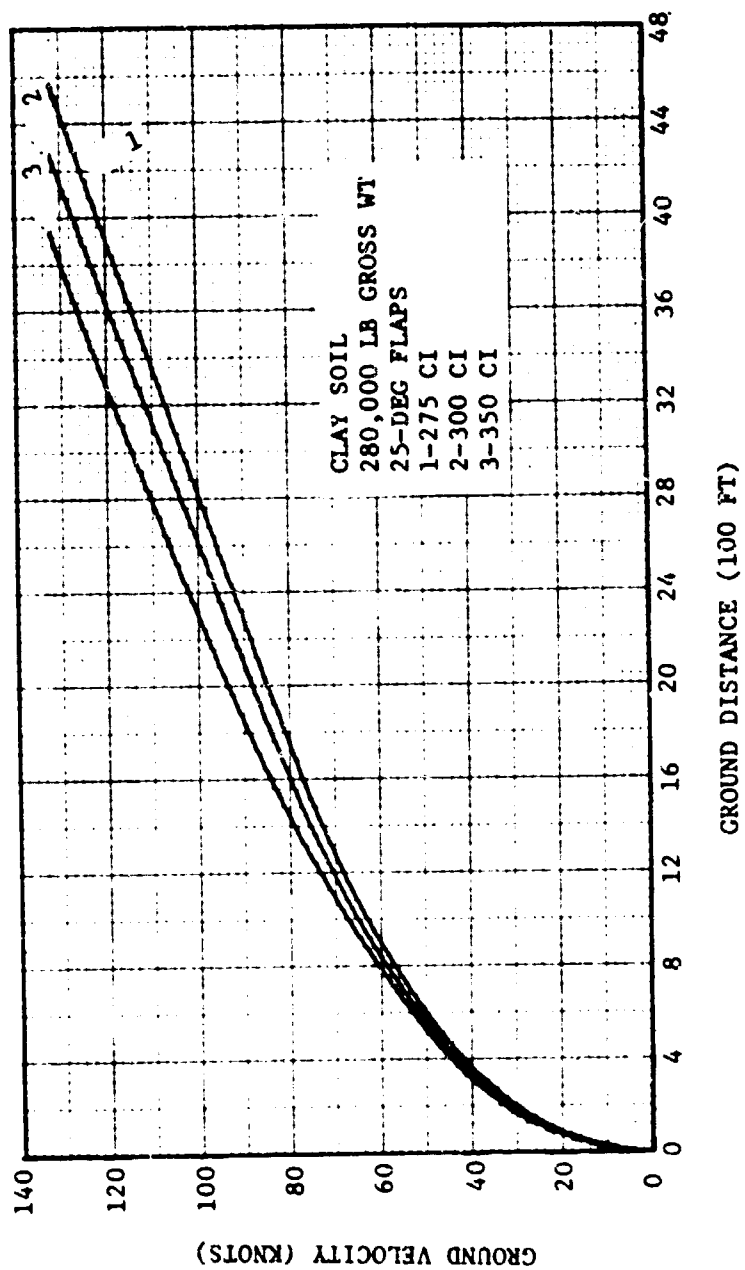


Figure 33. Airplane Velocity as a Function of Ground Distance for C-141 at 280,000 lb. Gross Weight

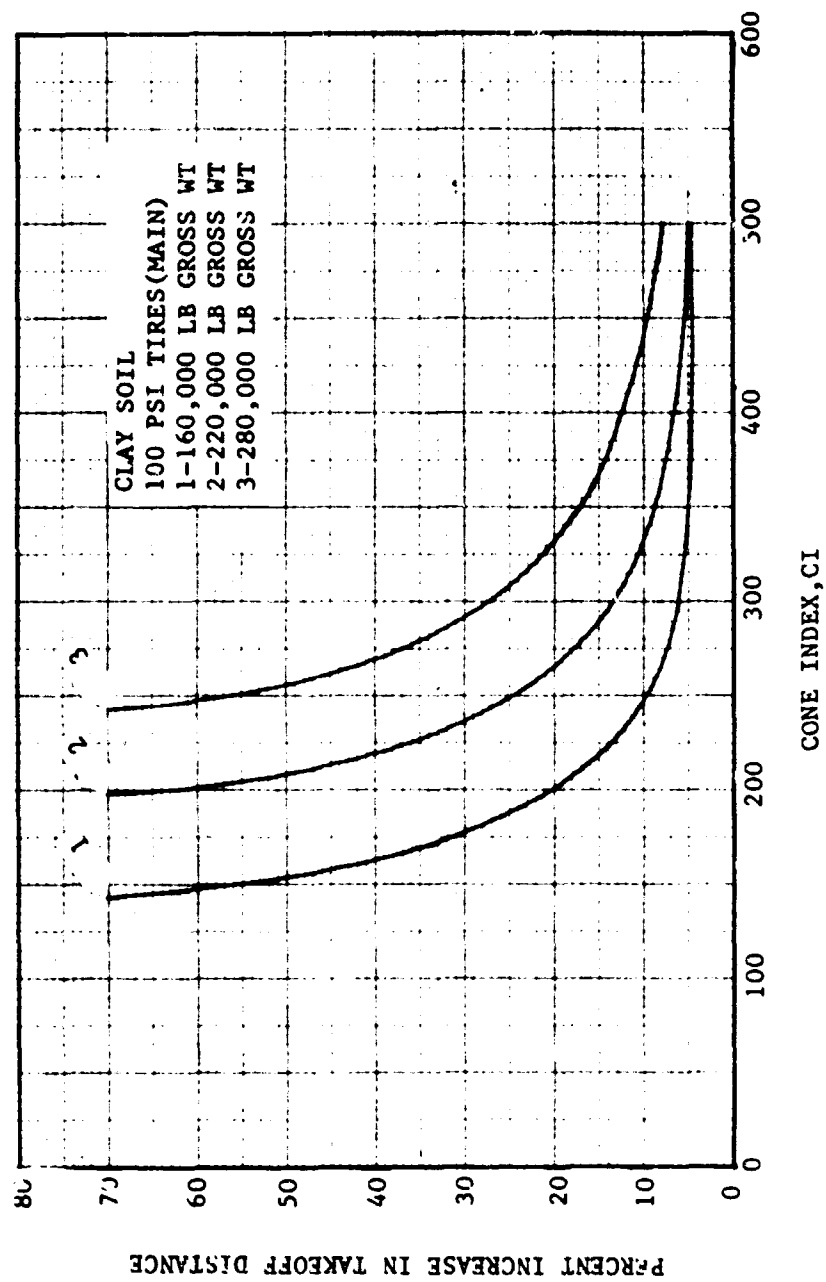


Figure 34 Percent Increase in Takeoff Distance Over Paved Surface for C-141 Aircraft

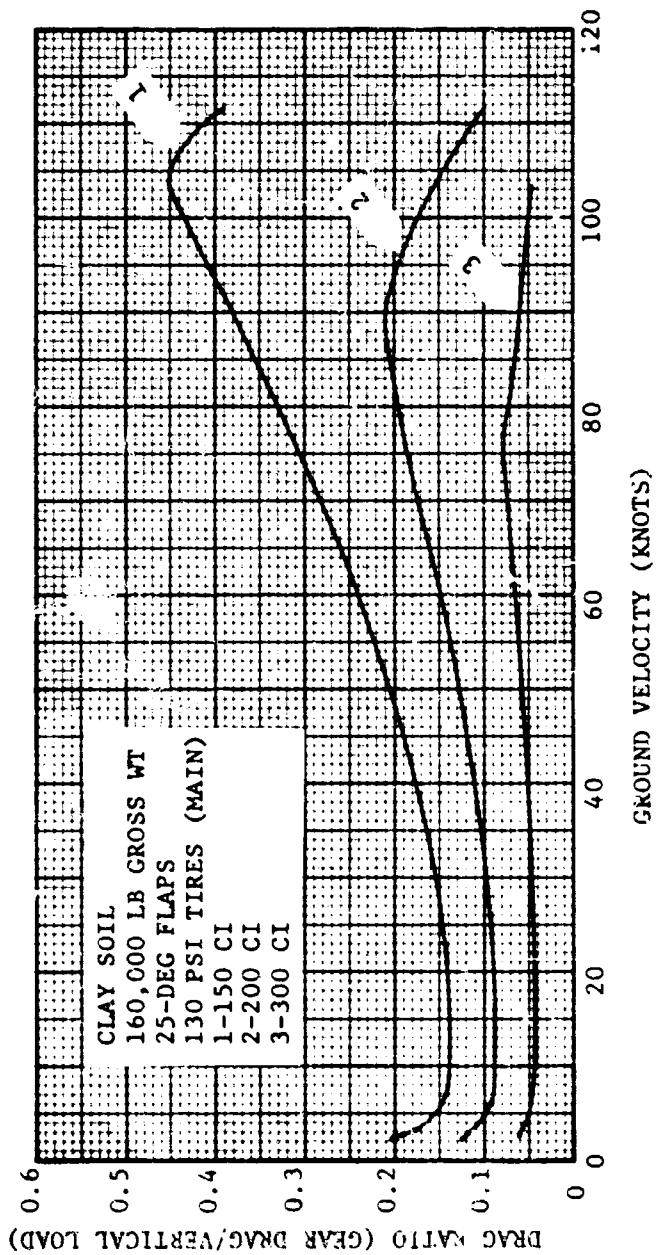


Figure 35 Drag Ratio as a Function of Ground Velocity for C-141 at 160,000 Lb. Gross Weight

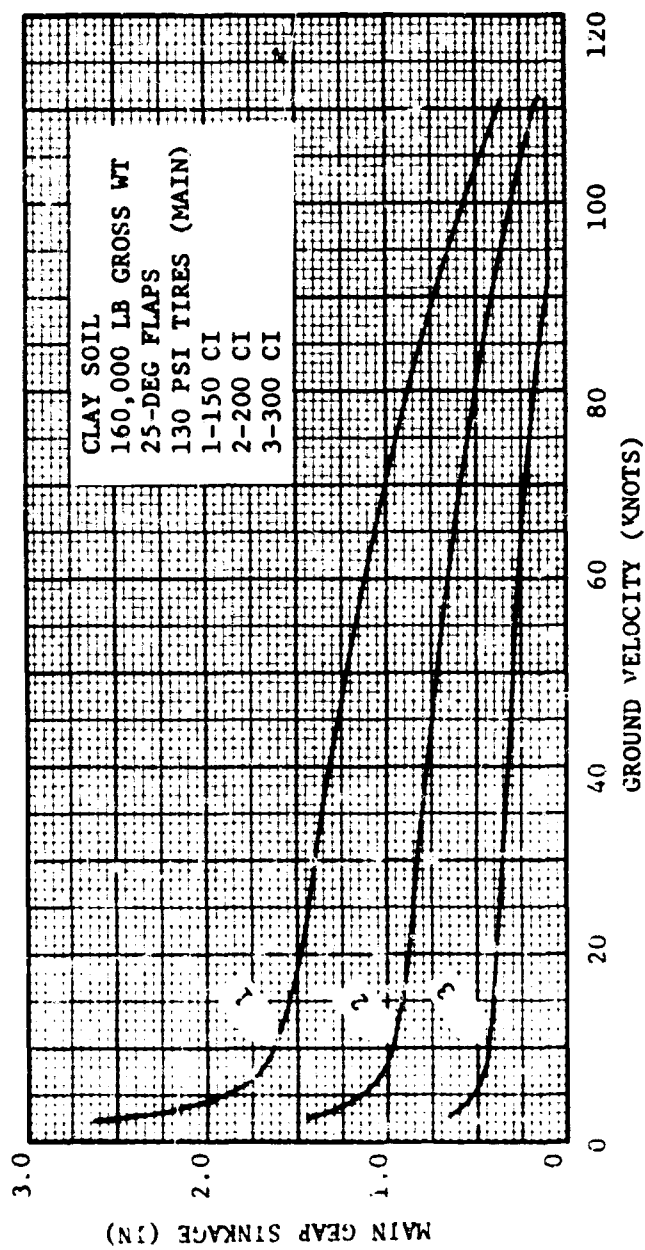


Figure 36 Soil Sinkage as a Function of Ground Velocity for C-141 at 160,000 Lb. Gross Weight

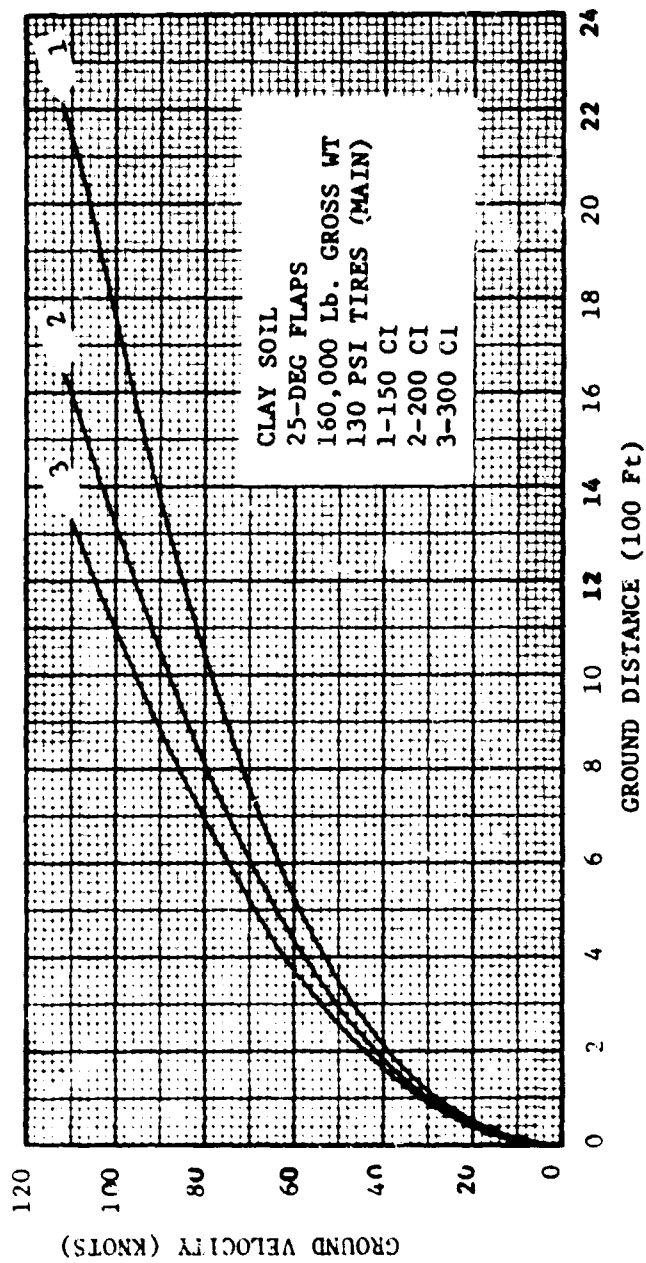


Figure 37. Airplane Velocity as a Function of Ground Distance for C-141 at 160,000 lb. Gross Weight

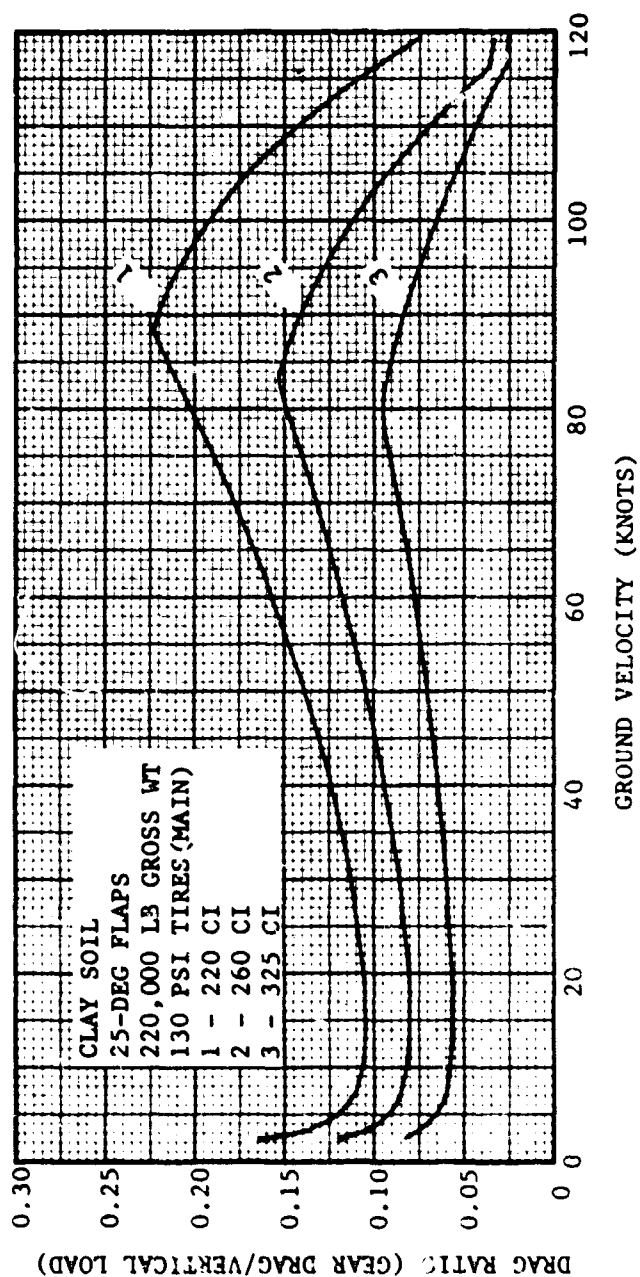


Figure 38 Drag Ratio as a Function of Ground Velocity for C-141 at 220,000 Lb. Gross Weight

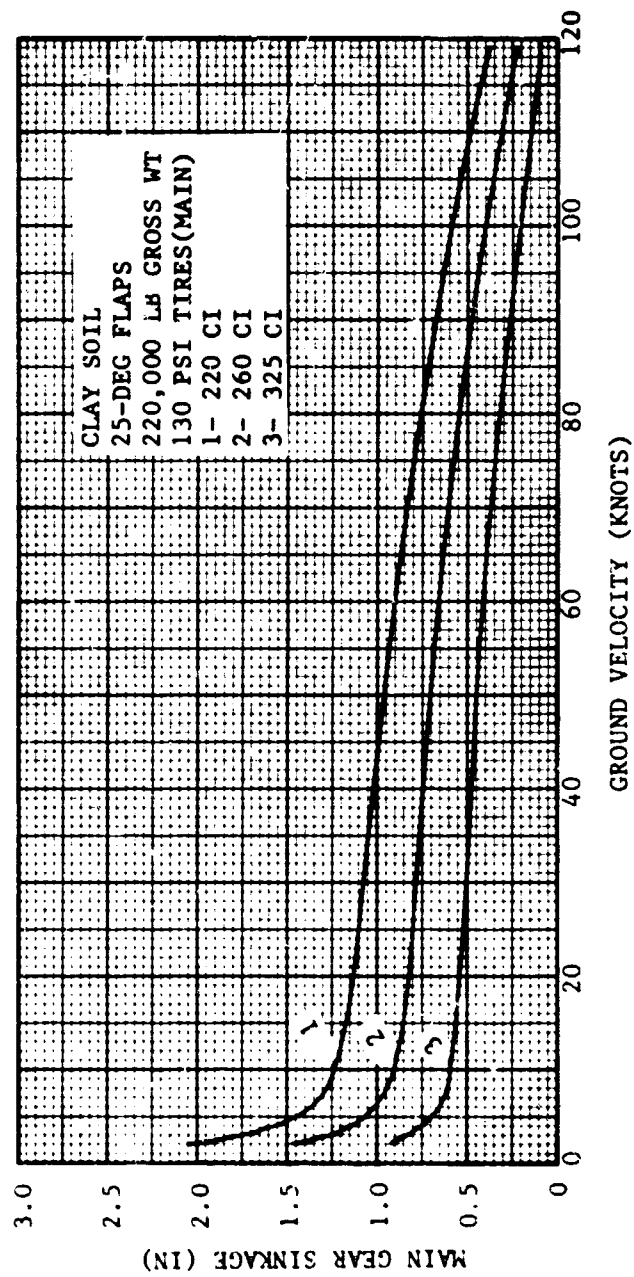


Figure 39 Soil Sinkage as a Function of Ground Velocity for C-141 at 220,000 Lb. Gross Weight

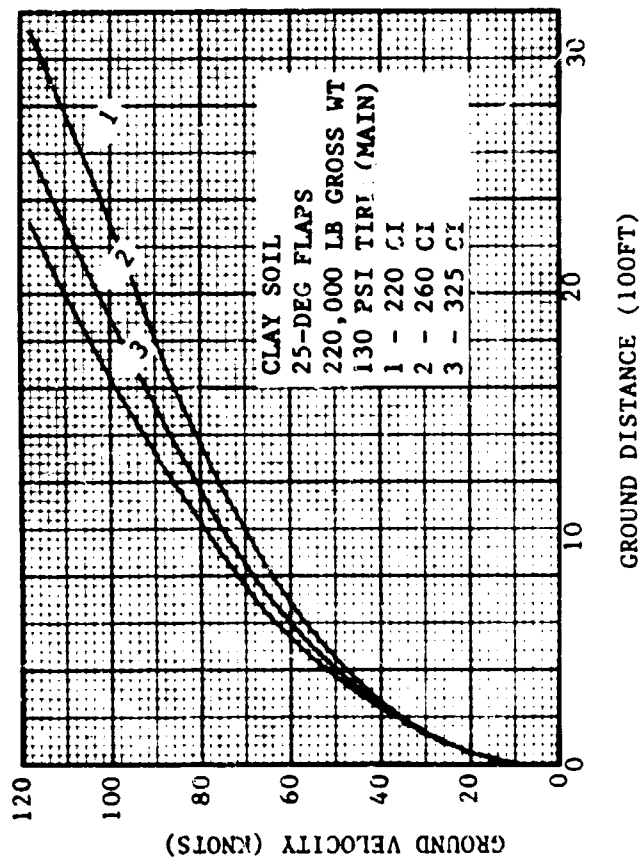


Figure 40. Airplane Velocity as a Function of Ground Distance for C-141 at 220,000 lb. Gross Weight

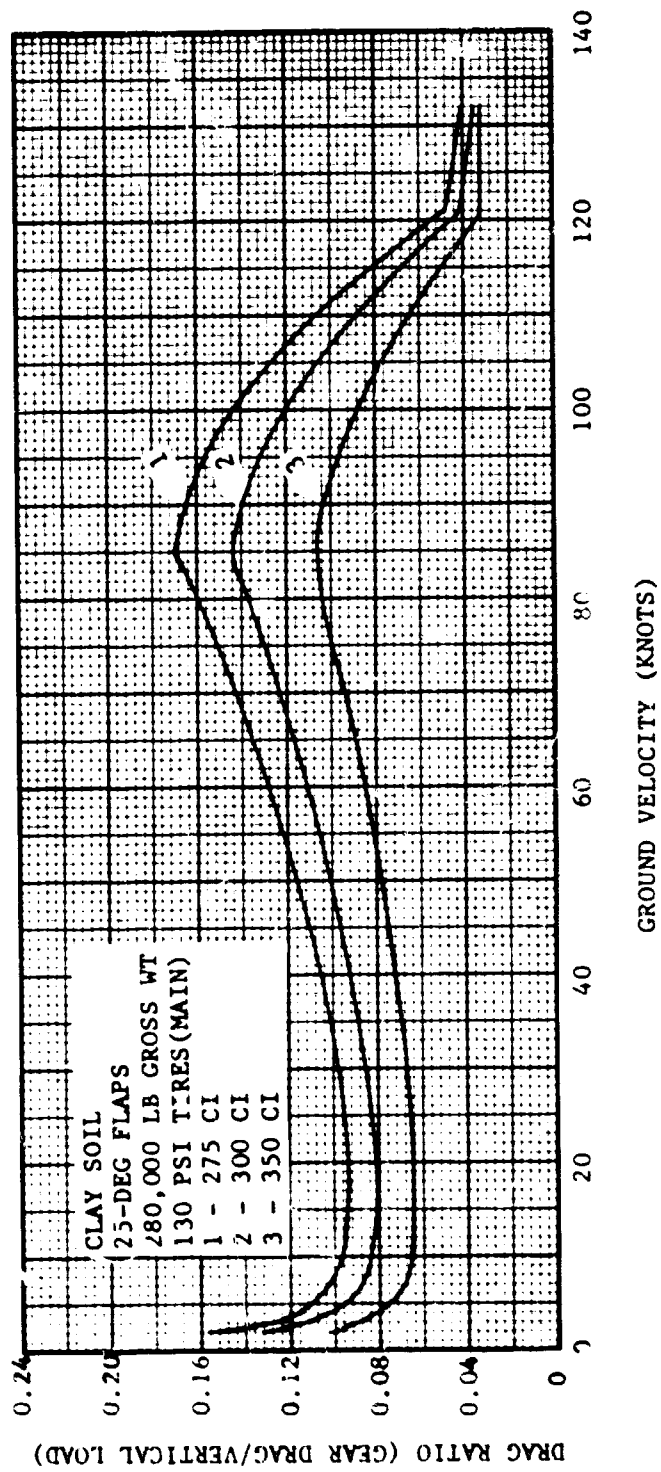


Figure 41 Drag ratio as a Function of Ground Velocity  
for C-141 at 280,000 Lb. Gross Weight

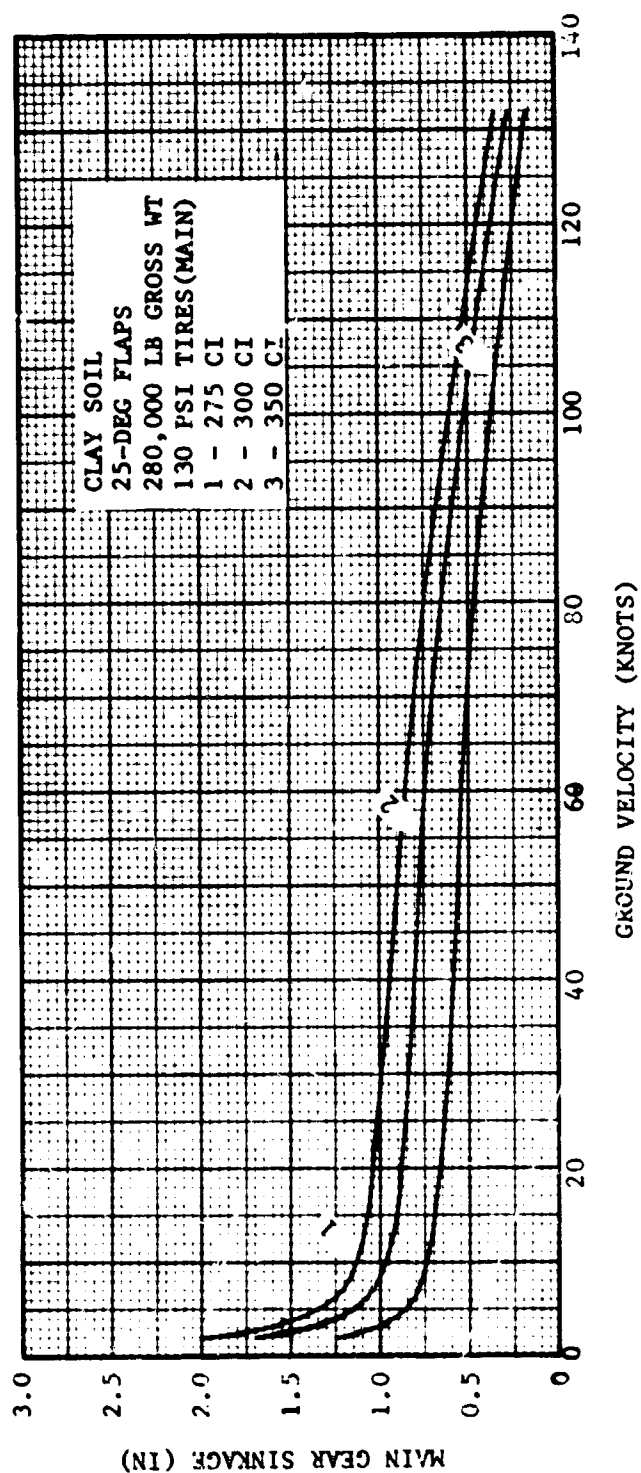


Figure 42 Soil Sinkage as a Function of Ground Velocity  
for C-141 at 280,000 Lb. Gross Weight

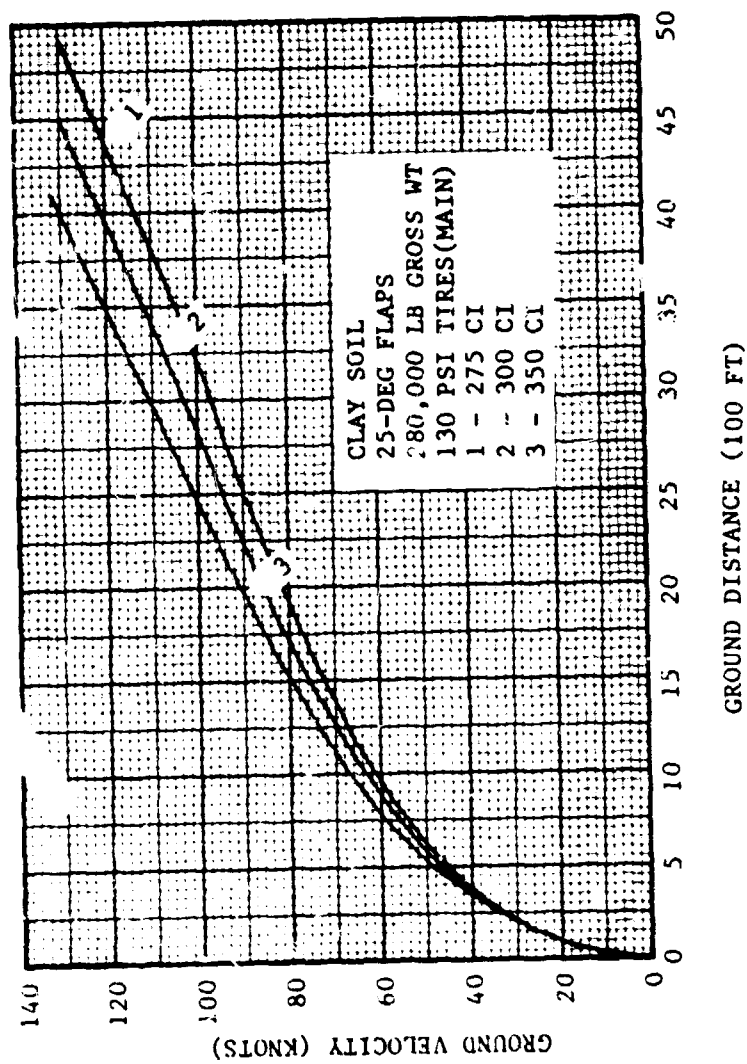


Figure 43. Airplane Velocity as a Function of Ground Distance for C-141 at 280,000 lb. Gross Weight

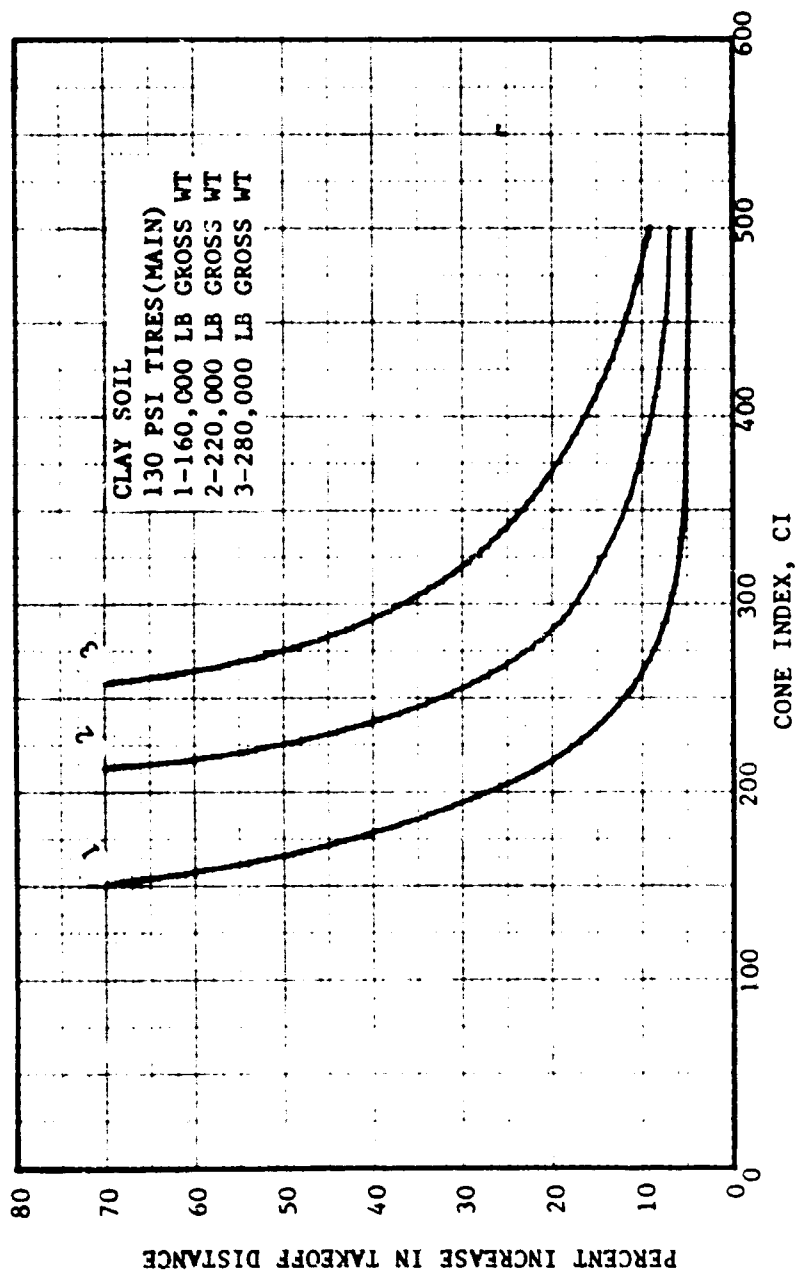


Figure 44 Percent Increase in Takeoff Distance Over Paved Surface for C-141 Aircraft

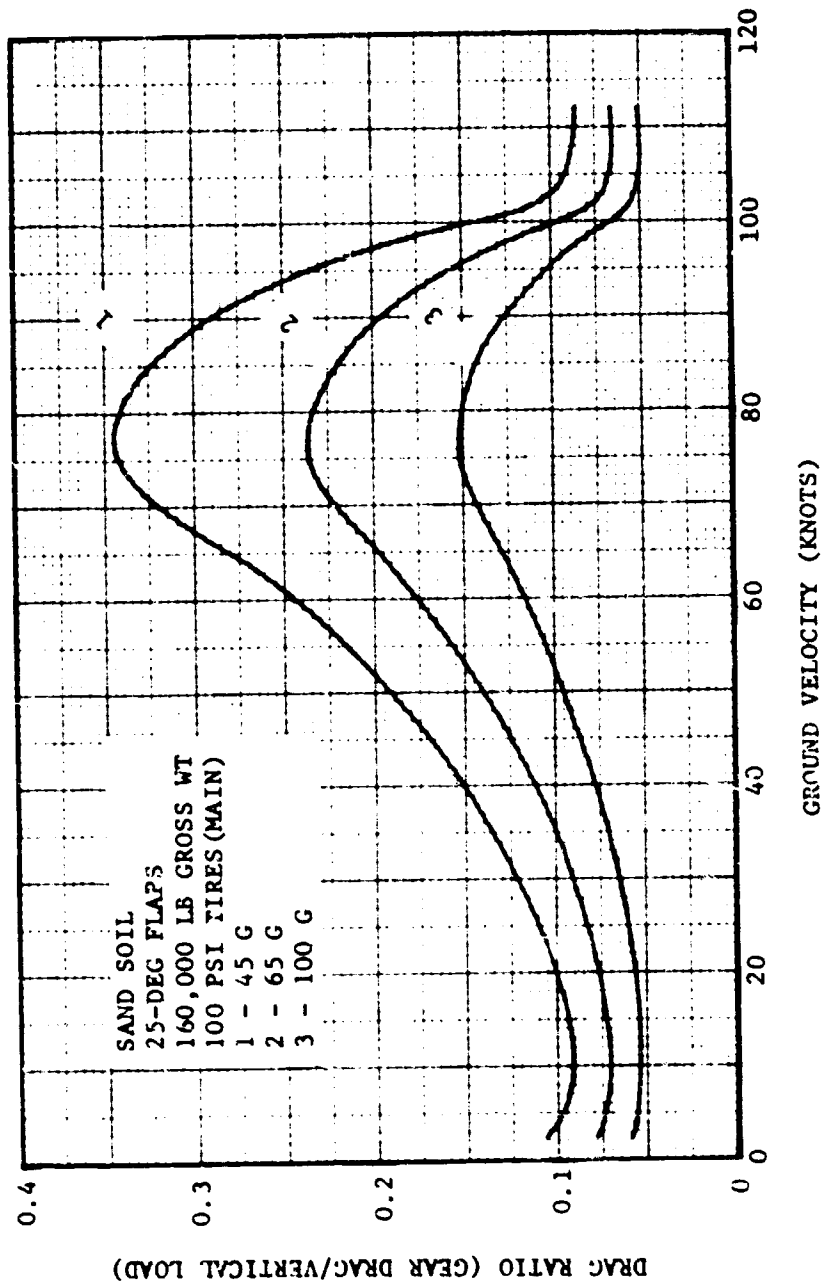


Figure 45 Drag Ratio as a Function of Ground Velocity  
 for C-141 Aircraft at 160,000 Lb. Gross Weight

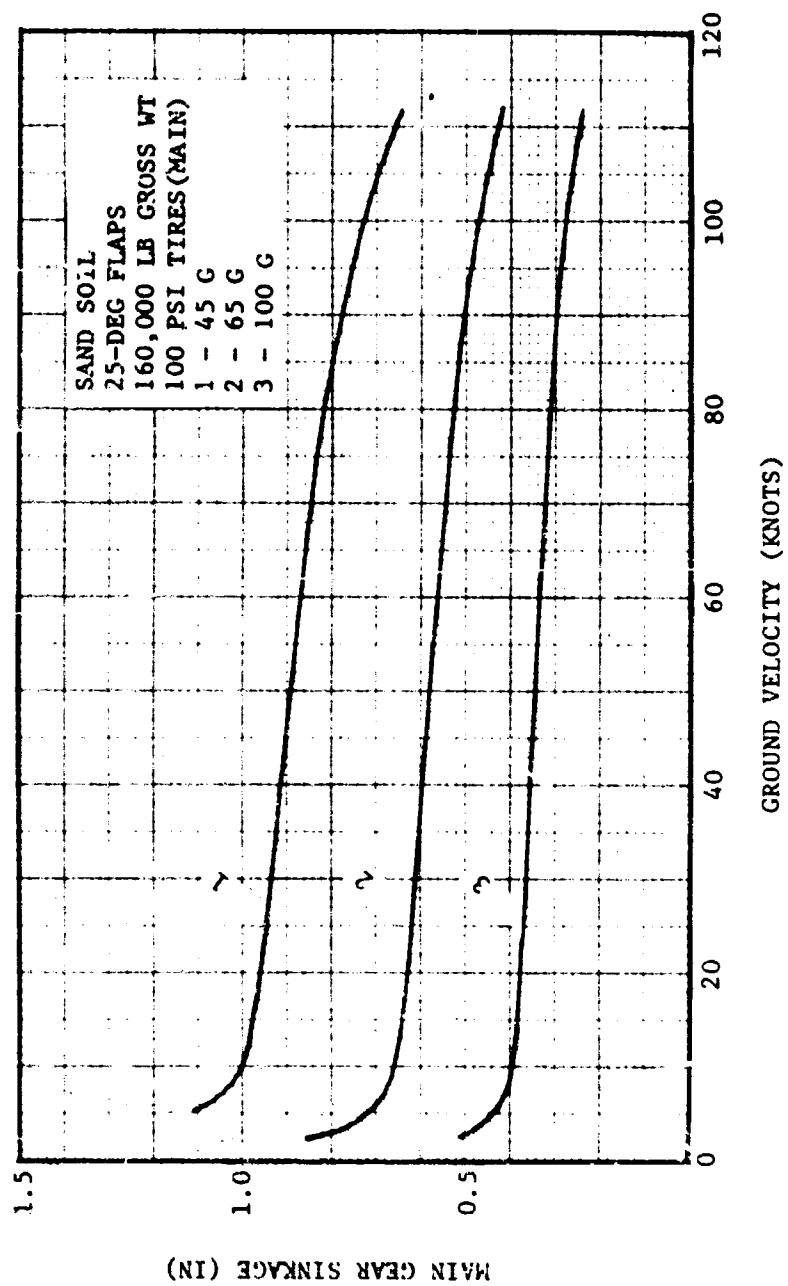


Figure 46 Main Gear Sinkage as a Function of Ground Velocity for C-141 at 160,000 Lb. Gross Weight

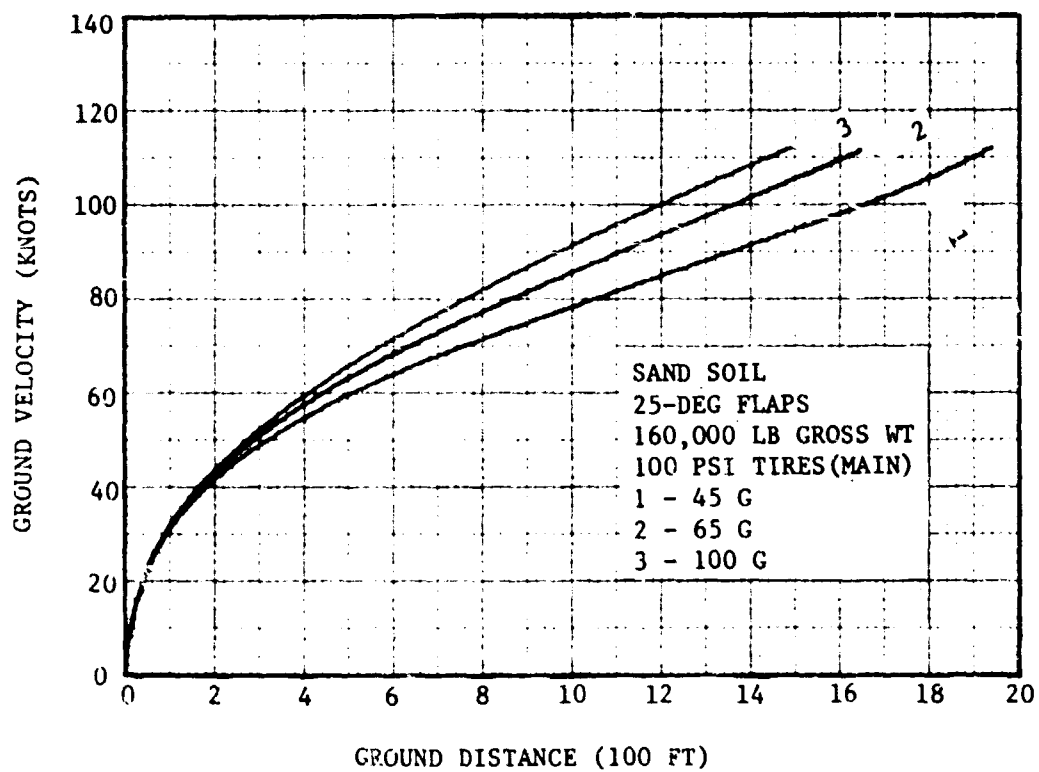


Figure 47. Airplane Velocity as a Function of Ground Distance for C-141 Aircraft at 160,000 lb. Gross Weight

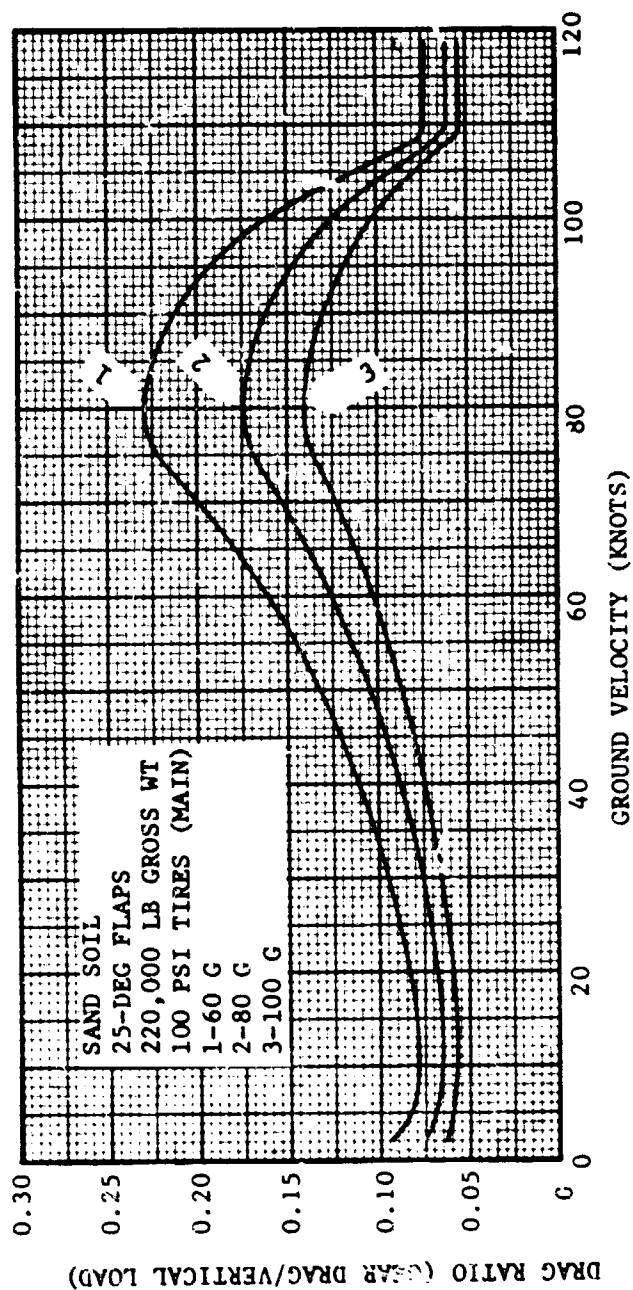


Figure 48 Drag Ratio as a Function of Ground Velocity for C-141 at 220,000 Lb. Gross Weight

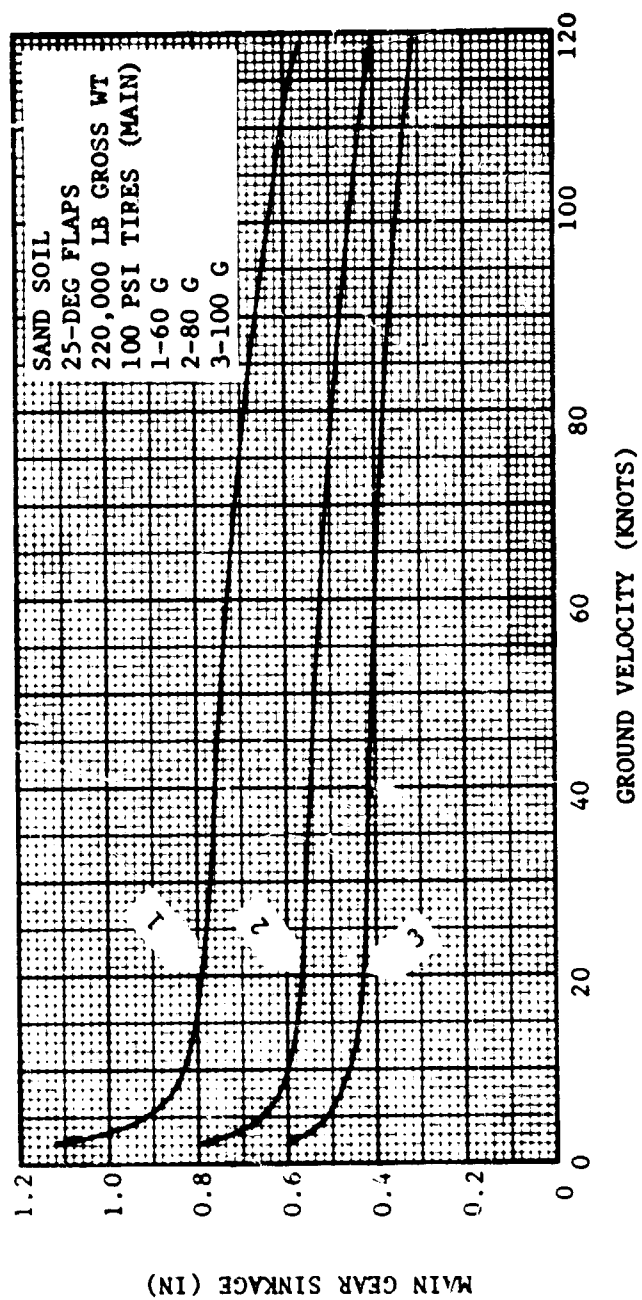


Figure 49 Soil Sinkage as a Function of Ground Velocity for C-141 at 220,000 lb. Gross Weight

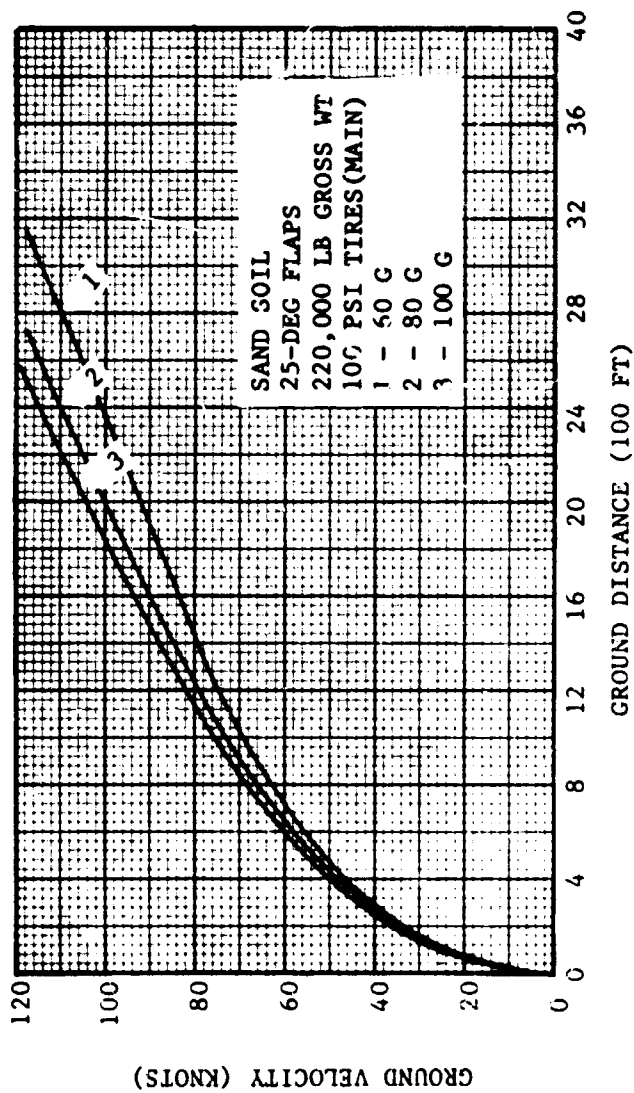


Figure 50. Airplane Velocity as a Function of Ground Distance for C-141 at 220,000 lb. Gross Weight

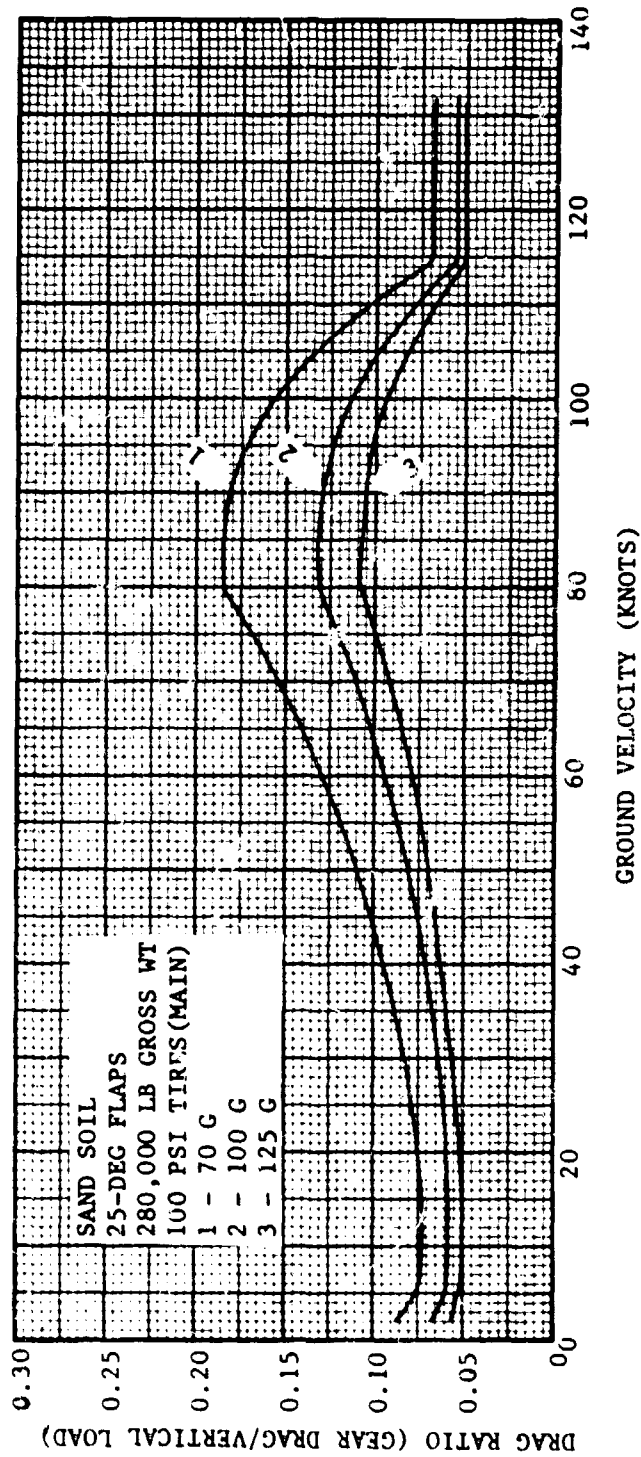


Figure 51 Drag Ratio as a Function of Ground Velocity for C-141 at 280,000 Lb. Gross Weight

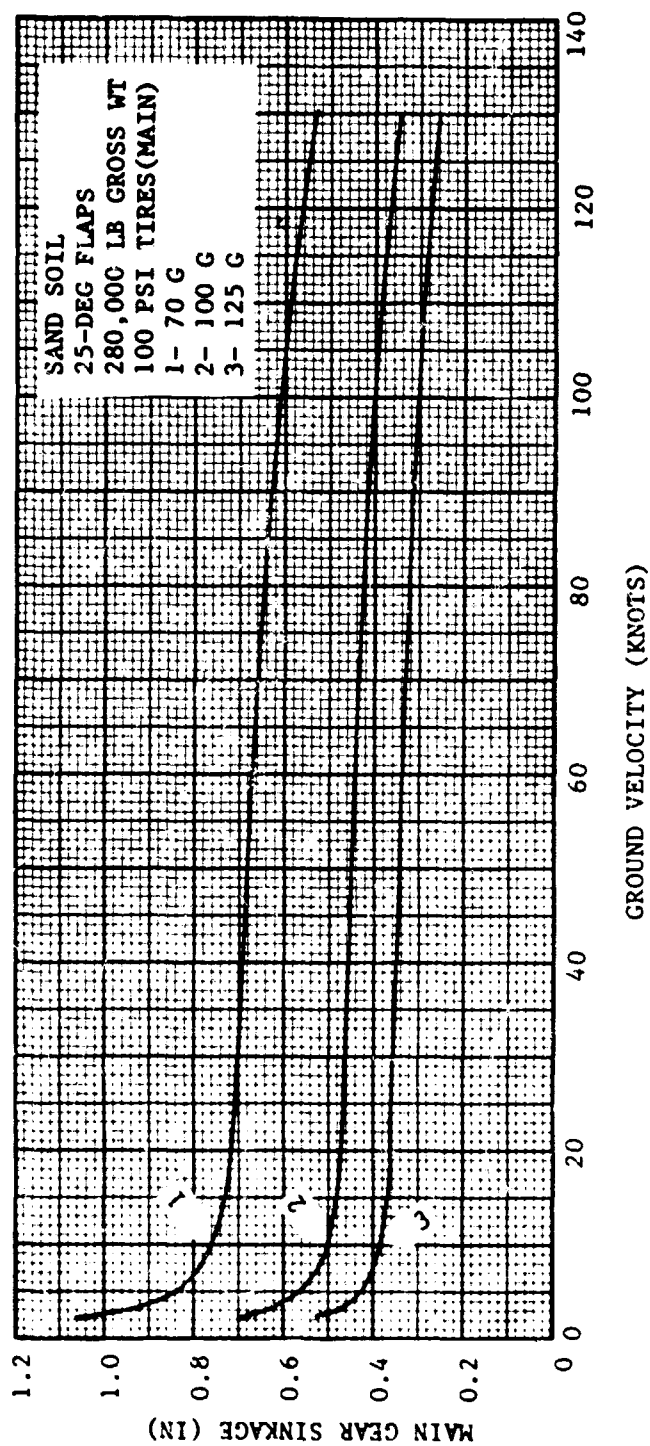


Figure 52 Soil Sinkage as a Function of Ground Velocity for C-141 at 280,000 Lb. Gross Weight

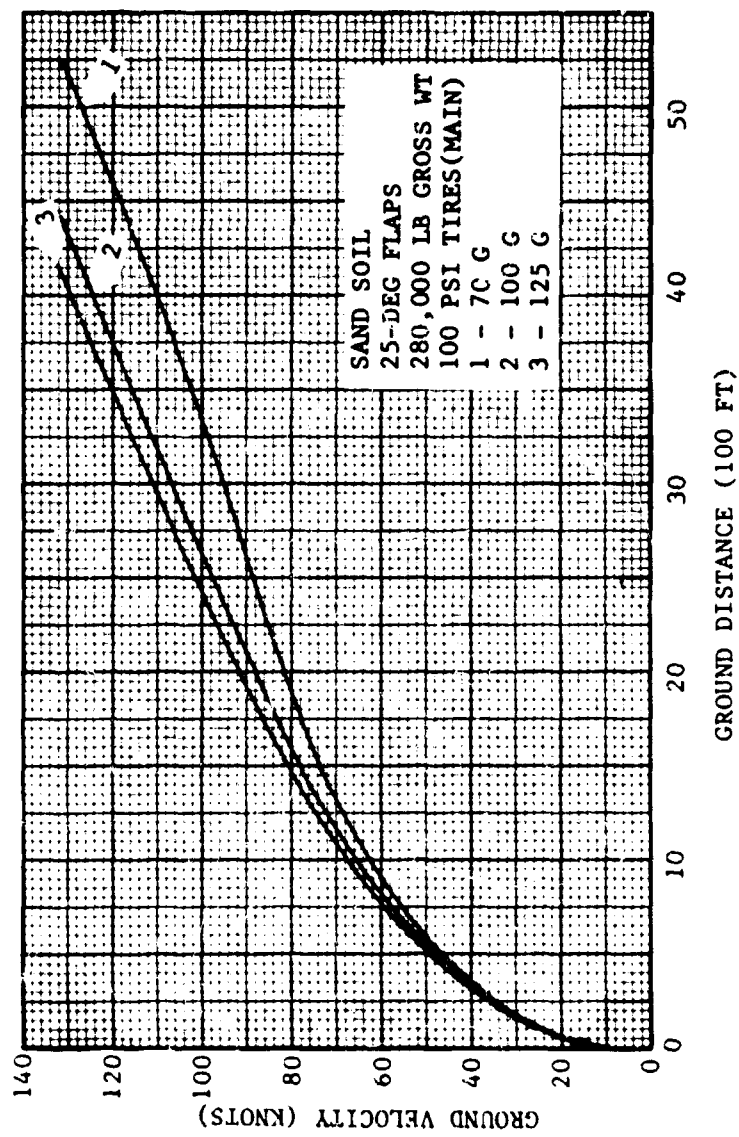


Figure 53. Airplane Velocity as a Function of Ground Distance for C-141 at 280,000 lb. Gross Weight

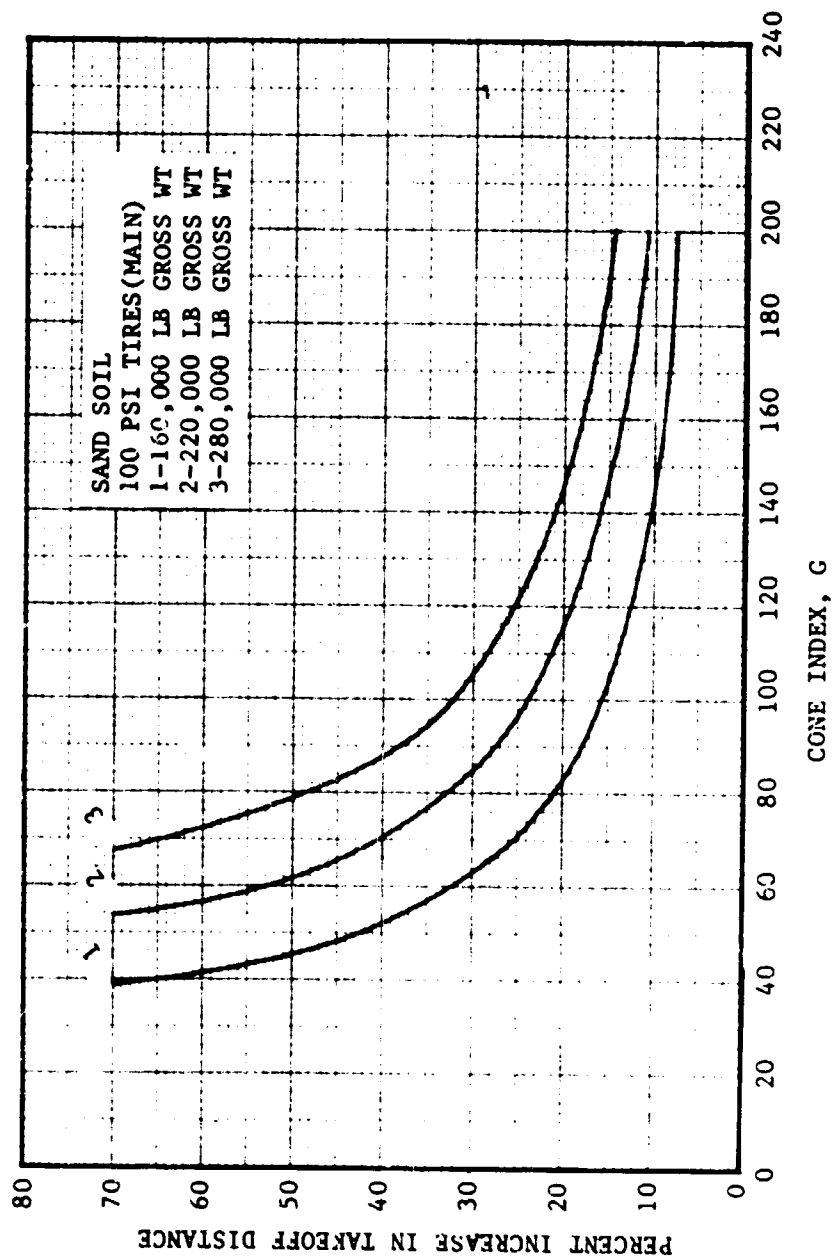


Figure 54 Percent Increase in Takeoff Distance Over Paved Surface for C-141 Aircraft

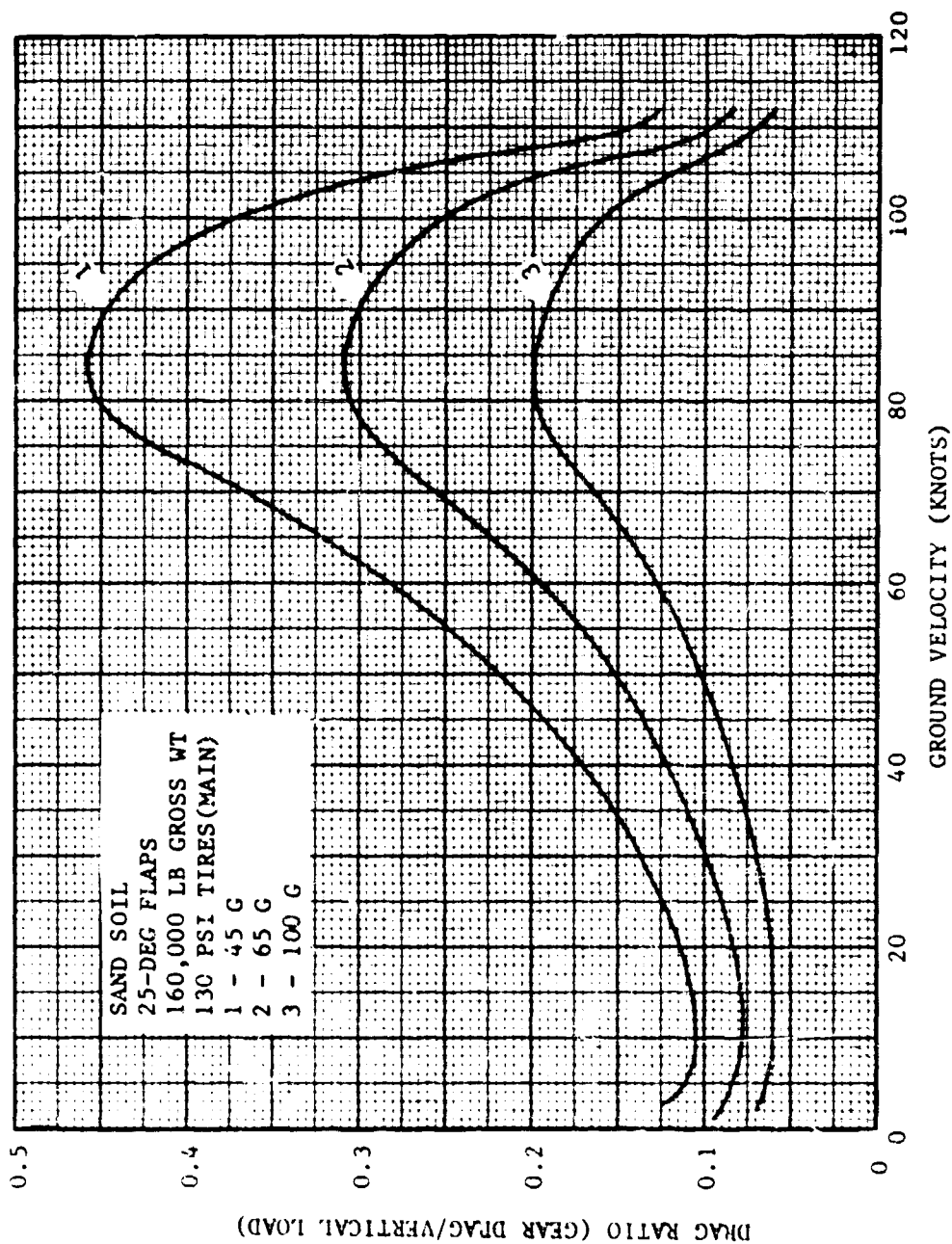


Figure 55 Drag Ratio as a Function of Ground Velocity for C-141 at 160,000 lb. Gross Weight

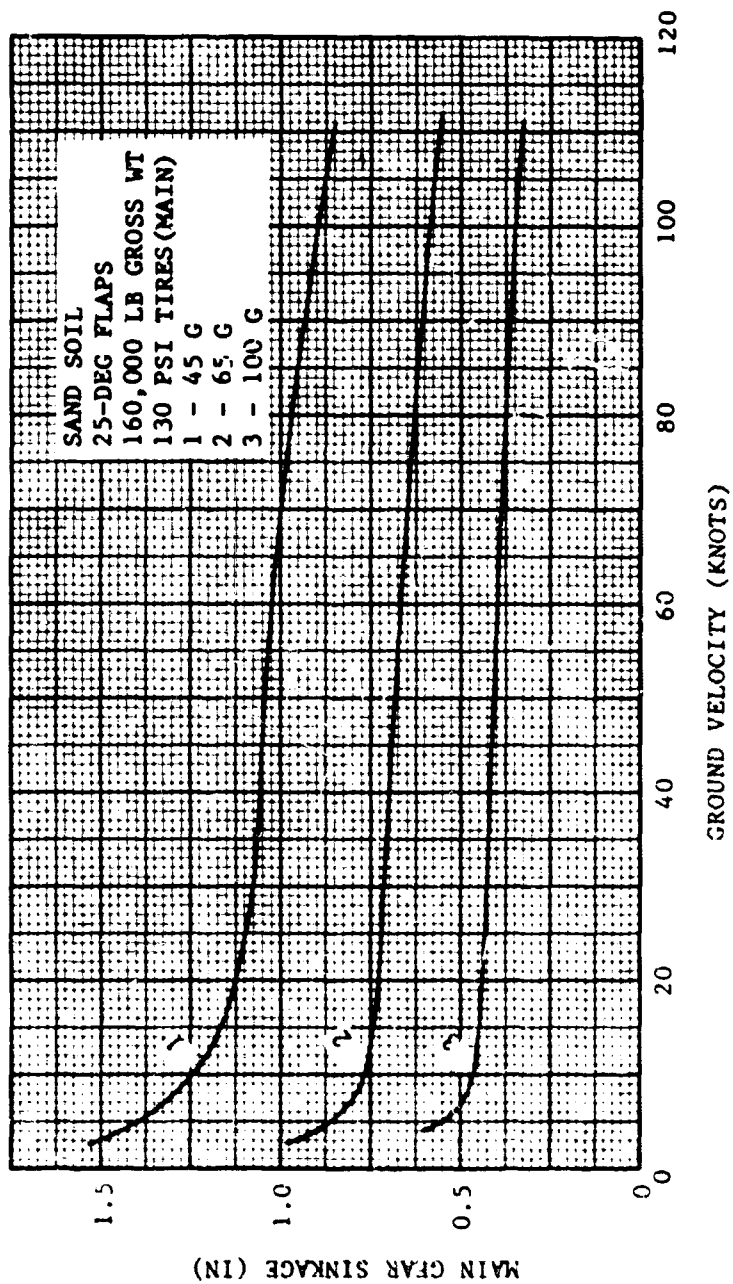


Figure 56 Soil Sinkage as a Function of Ground Velocity for C-141 at 160,000 Lb. Gross Weight

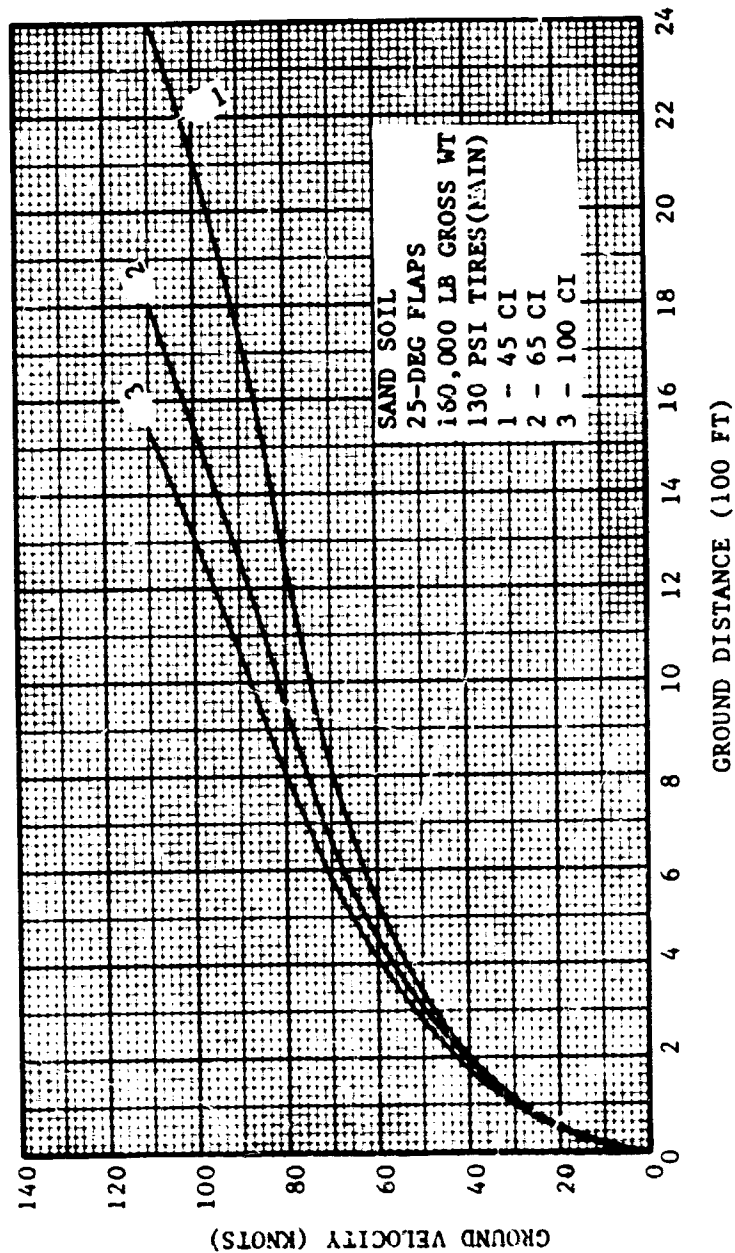


Figure 57. Airplane Velocity as a Function of Ground Distance for C-141 at 160,000 lb. Gross Weight

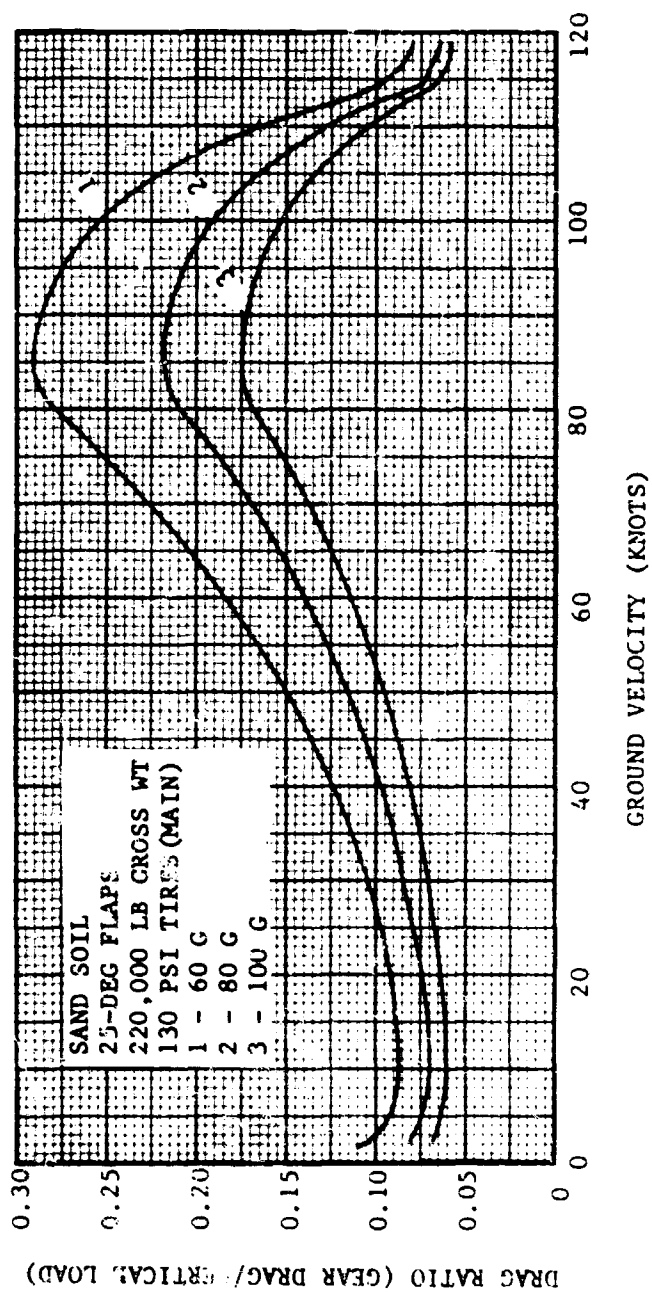


Figure 58 Drag Ratio as a Function of Ground Velocity for C-141 at 220,000 Lb. Gross Weight

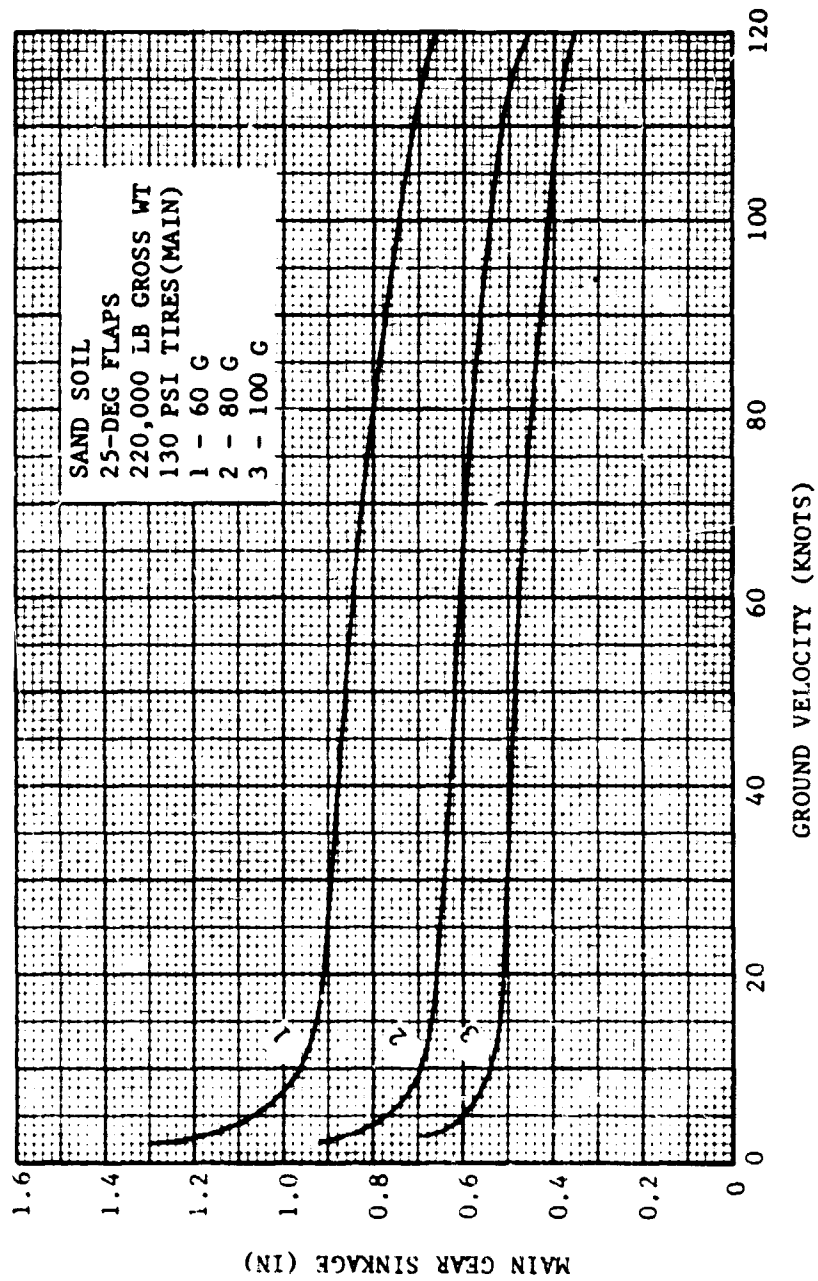


Figure 59 Soil Sinkage as a Function of Ground Velocity for C-141 at 220,000 Lb. Gross Weight

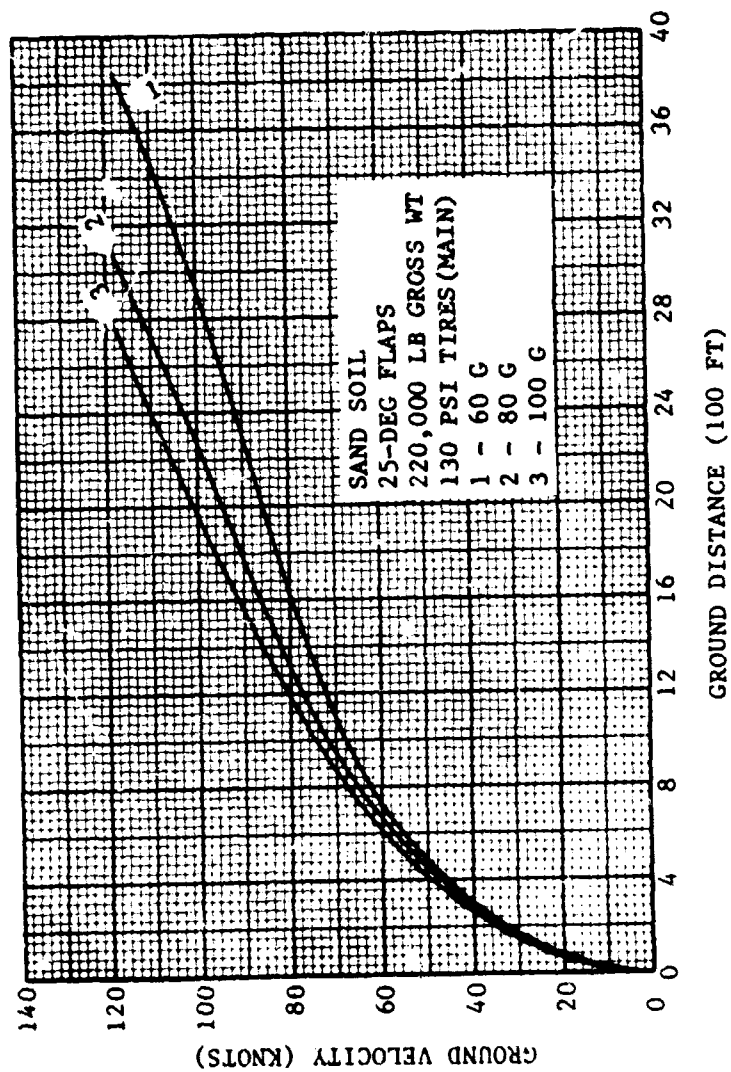


Figure 60. Airplane Velocity as a Function of Ground Distance for C-141 at 220,000 lb. Gross Weight

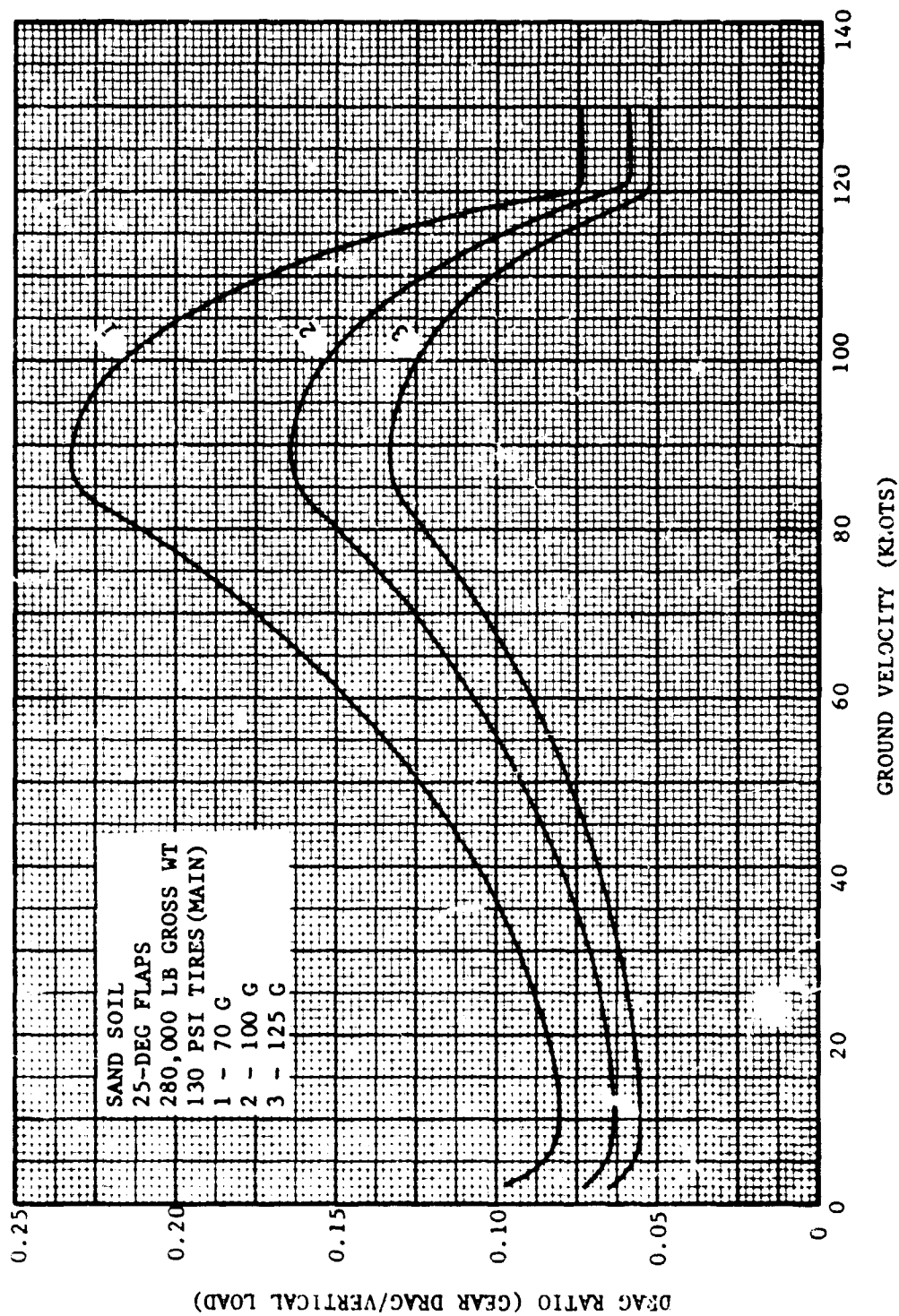


Figure 61 Drag Ratio as a Function of Ground Velocity for  
C-141 at 280,000 lb. Gross Weight

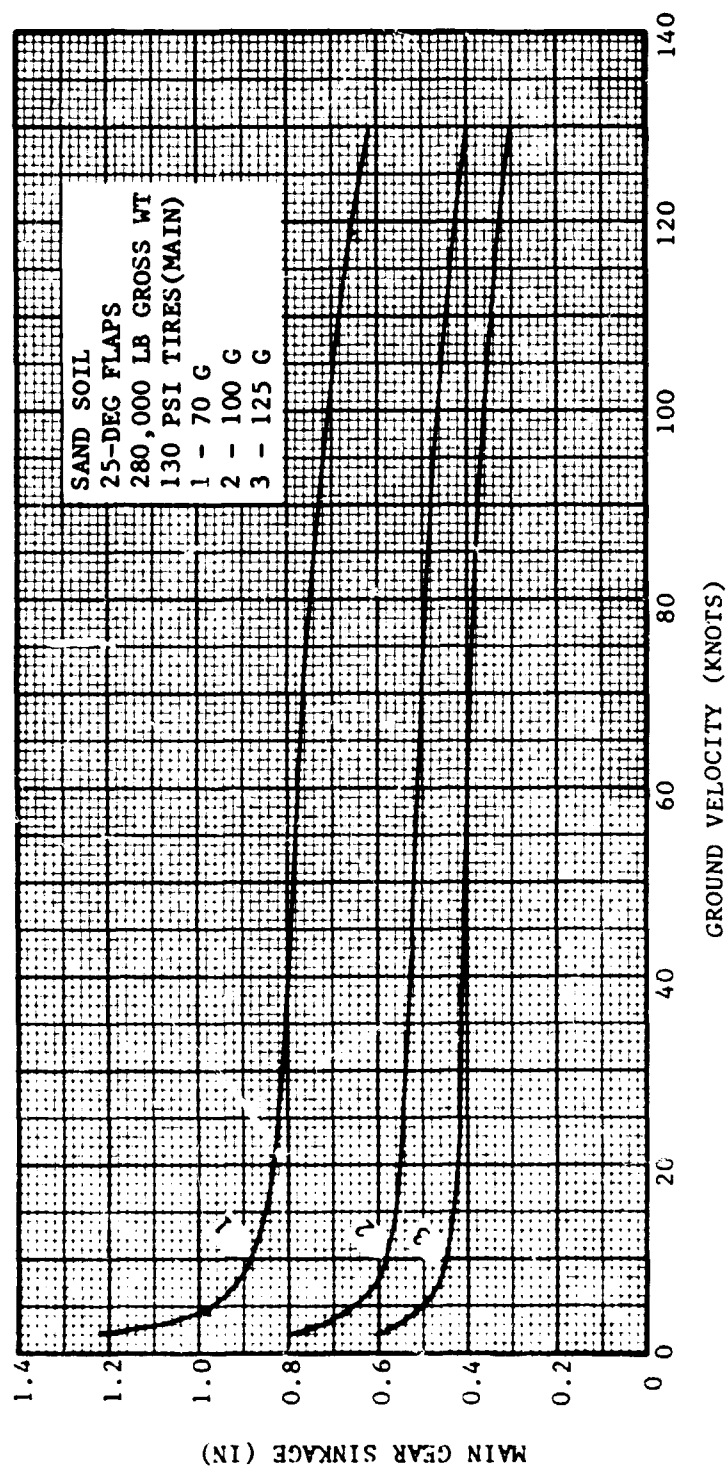


Figure 62 Soil Sinkage as a Function of Ground Velocity for C-141 at 280,000 Lb. Gross Weight

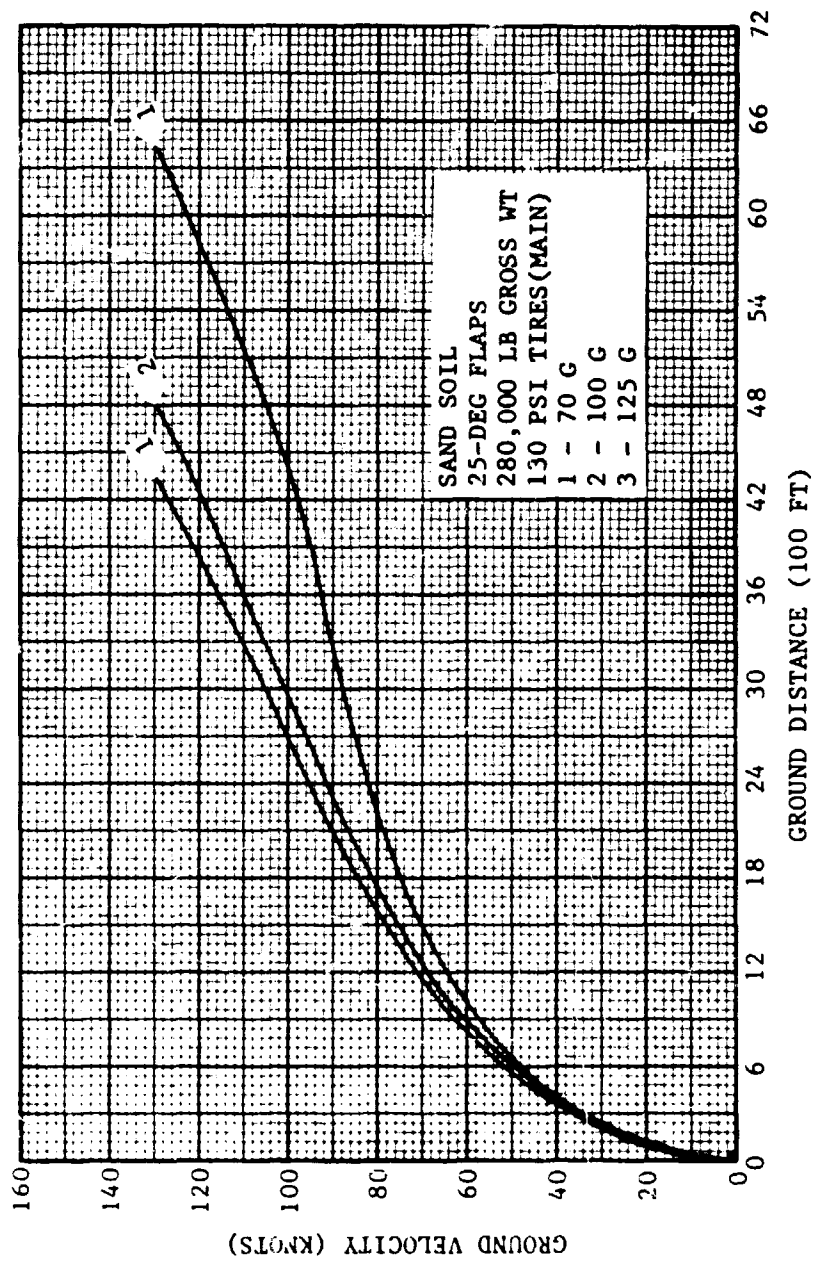


Figure 63. Airplane Velocity as a Function of Ground Distance for C-141 at 280,000 lb. Gross Weight

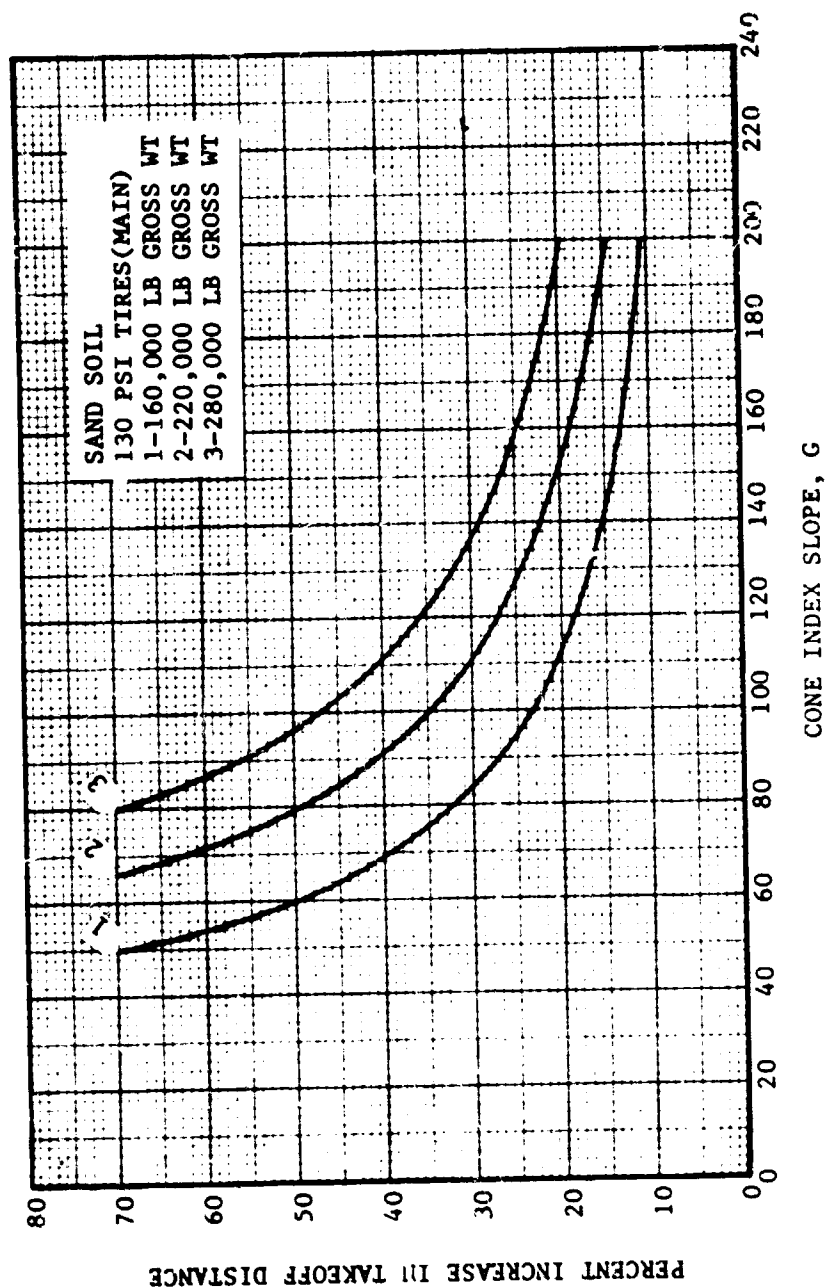


Figure 64 Percent Increase in Takeoff Distance Over Paved Surface for C-141 Aircraft

## SECTION VI

### PERFORMANCE OF C-5 AIRCRAFT OPERATING ON CLAY AND SANDY AIRFIELDS

Discussion - One of the basic design requirements of the C-5 aircraft is to operate on semi-prepared soil airfields. To satisfy this requirement, some means of predicting the takeoff distance analytically is necessary for construction of flight performance handbook charts, since full scale testing for each configuration is prohibited from a cost standpoint. The curves presented in this section are of the type which could provide handbook information. The curves are, of course, based only on a limited test program for full scale aircraft but reasonably accurate predictions appear to be possible.

Results - The format for presenting the C-5 data is the same as that for the C-141. A paved surface takeoff distance curve is presented in Figure 65 for a reference since all soil takeoff distance curves (Figures 78, 88, 98 and 108) are presented as a percent increase in the paved distance. Paved takeoff distances calculated with the program were shorter than the values calculated by Lockheed because of our simplification of the rotation phase by elimination of the varying lift and drag coefficients (see Appendix F for further details and computer data).

Table II gives an index of the data presented for the C-5. Two soil types with two tire pressures, three gross weights and three soil strengths were used to obtain the figures. Summary figures (78, 88, 98 and 108) may be compared to see the effects of parameter change on the increase in takeoff distance. Figures 78 and 88 show the difference in takeoff distance because of a change in tire pressure on clay. Figures 98 and 108 show a similar change for sand. Comparison of Figures 78 and 98 will show the effect of changing from clay to sand for the same weight and tire pressure conditions. Figures 88 and 108 give a comparison of changing from clay to sand for a higher tire pressure.

TABLE 2

## C-5 CONFIGURATION SUMMARY

Gross Weight	Surface Type	Surface Strength (CI for Clay) ( G for Sand)	Tire Pressure	Figure Number
400,000 Lb.	Paved	-	-	66
500,000 Lb.	Paved	-	-	67
571,000 Lb.	Paved	-	-	68
400,000 Lb.	Clay	175,200,250	95 Psi	69
400,000 Lb.	Clay	175,200,250	95 Psi	70
400,000 Lb.	Clay	175,200,250	95 Psi	71
500,000 Lb.	Clay	200,225,275	95 Psi	72
500,000 Lb.	Clay	200,225,275	95 Psi	73
500,000 Lb.	Clay	200,225,275	95 Psi	74
571,000 Lb.	Clay	225,250,300	95 Psi	75
571,000 Lb.	Clay	225,250,300	95 Psi	76
571,000 Lb.	Clay	225,250,300	95 Psi	77
400,000 Lb.	Clay	175,200,250	120 Psi	79
400,000 Lb.	Clay	175,200,250	120 Psi	80
400,000 Lb.	Clay	175,200,250	120 Psi	81
500,000 Lb.	Clay	200,225,275	120 Psi	82
500,000 Lb.	Clay	200,225,275	120 Psi	83
500,000 Lb.	Clay	200,225,275	120 Psi	84
571,000 Lb.	Clay	225,250,300	120 Psi	85
571,000 Lb.	Clay	225,250,300	120 Psi	86
571,000 Lb.	Clay	225,250,300	120 Psi	87
400,000 Lb.	Sand	75,100,125	95 Psi	89
400,000 Lb.	Sand	75,100,125	95 Psi	90
400,000 Lb.	Sand	75,100,125	95 Psi	91
500,000 Lb.	Sand	80,110,150	95 Psi	92
500,000 Lb.	Sand	80,110,150	95 Psi	93
500,000 Lb.	Sand	80,110,150	95 Psi	94
571,000 Lb.	Sand	85,120,175	95 Psi	95
571,000 Lb.	Sand	85,120,175	95 Psi	96
571,000 Lb.	Sand	85,120,175	95 Psi	97
400,000 Lb.	Sand	75,100,125	120 Psi	99
400,000 Lb.	Sand	75,100,125	120 Psi	100
400,000 Lb.	Sand	75,100,125	120 Psi	101
500,000 Lb.	Sand	80,110,150	120 Psi	102
500,000 Lb.	Sand	80,110,150	120 Psi	103
500,000 Lb.	Sand	80,110,150	120 Psi	104
571,000 Lb.	Sand	85,120,175	120 Psi	105
571,000 Lb.	Sand	85,120,175	120 Psi	106
571,000 Lb.	Sand	85,120,175	120 Psi	107

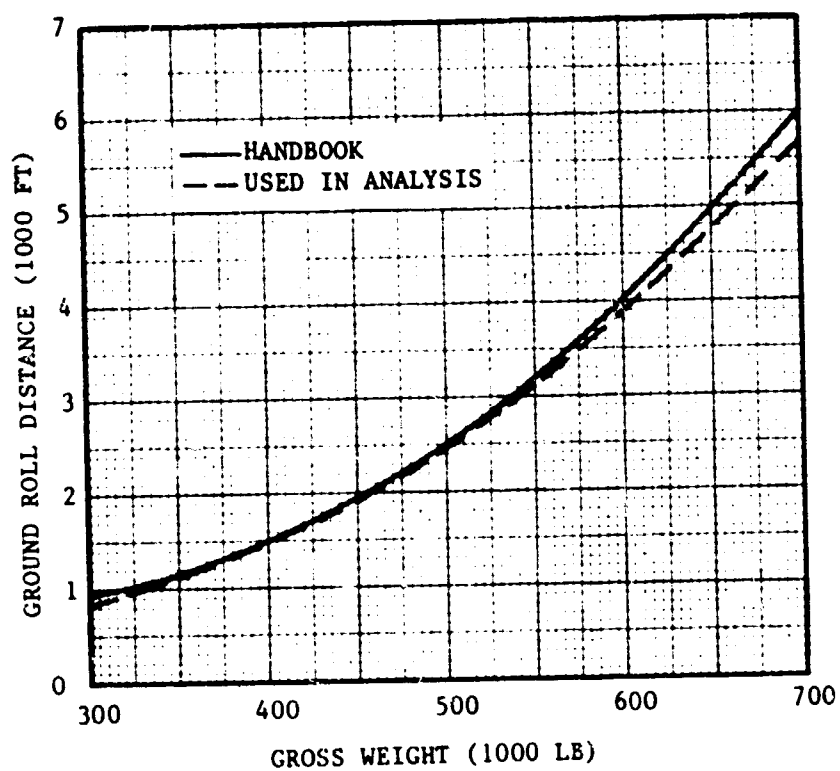


Figure 65 C-5 Paved Surface Ground Roll Distance as a Function of Gross Weight

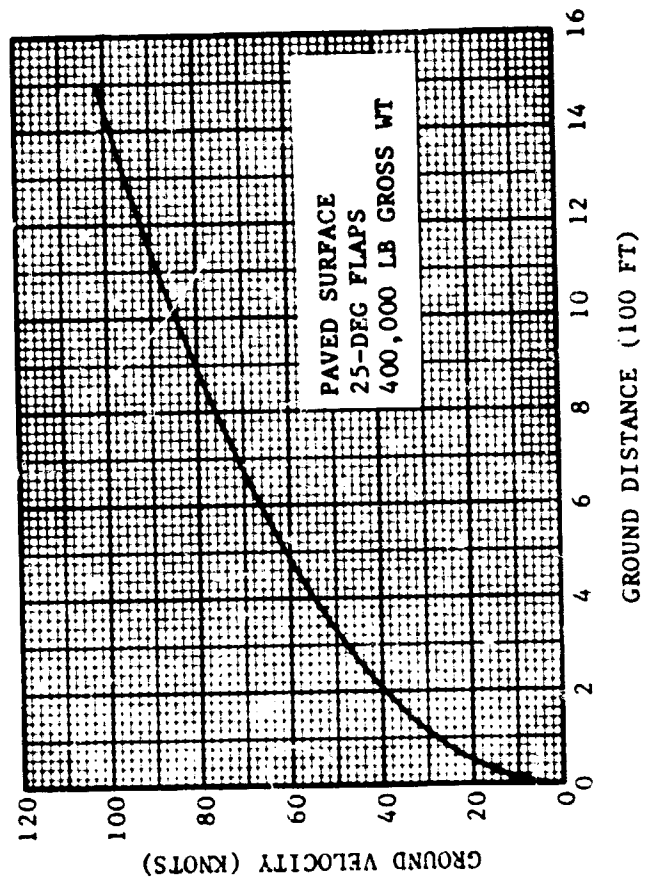


Figure 66. Airplane Velocity as a Function of Ground Distance for C-5 at 400,000 lb. Gross Weight

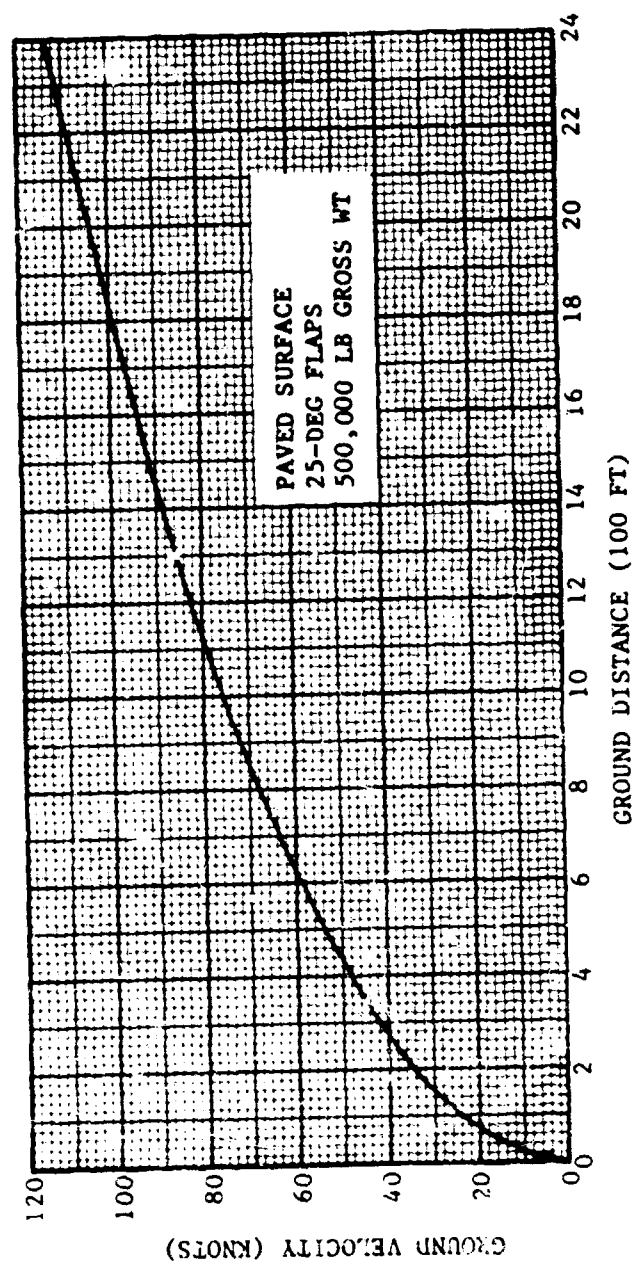


Figure 67. Airplane Velocity as a Function of Ground Distance for C-5 at 500,000 lb. Gross Weight

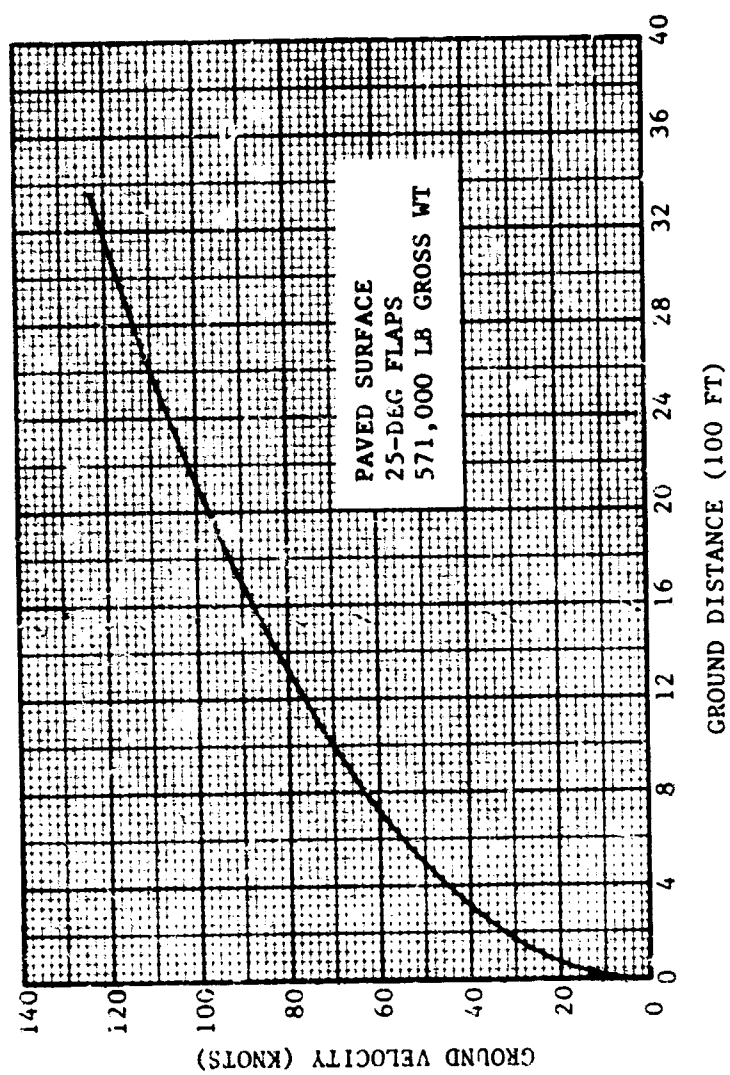


Figure 68. Airplane Velocity as a Function of Ground Distance for C-5 at 571,000 lb. Gross Weight

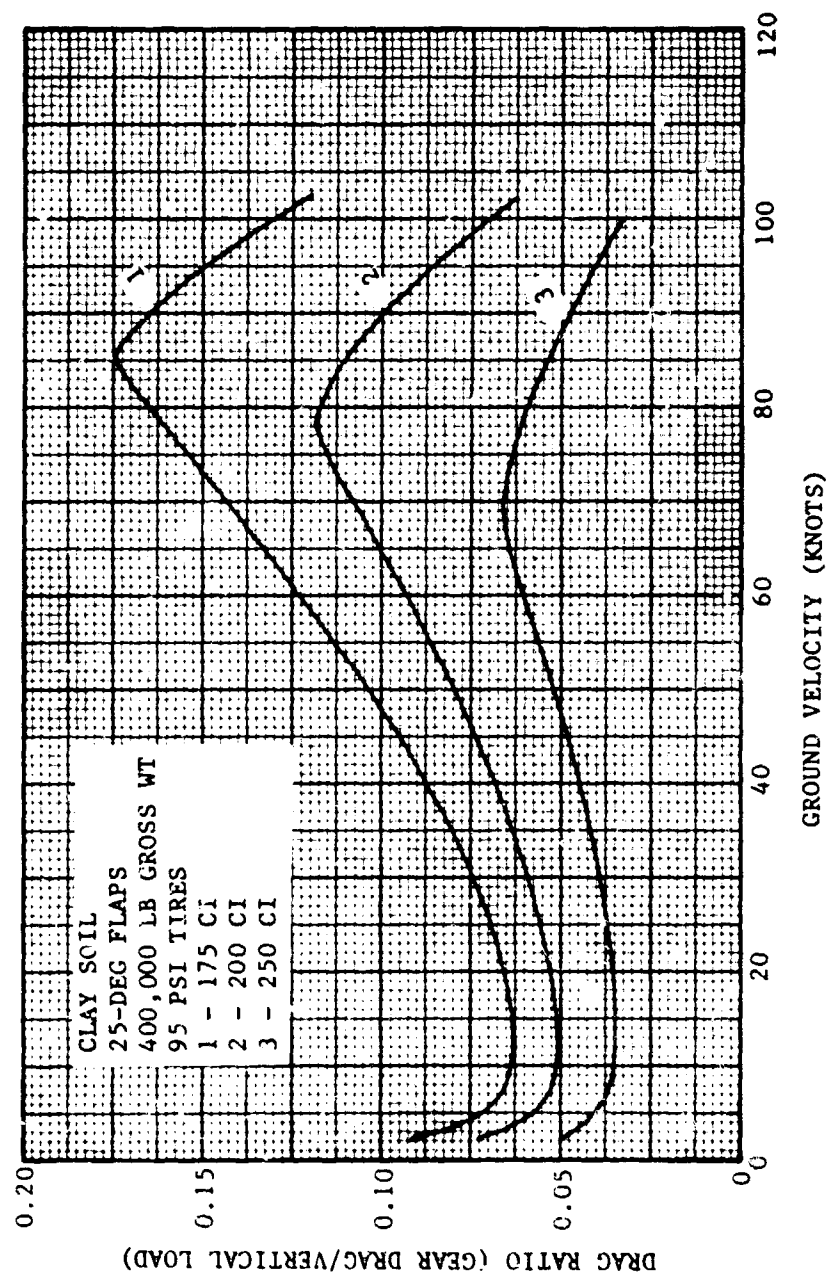


Figure 69 Drag Ratio as a Function of Ground Velocity for C-5 at 400,000 Lb. Gross Weight

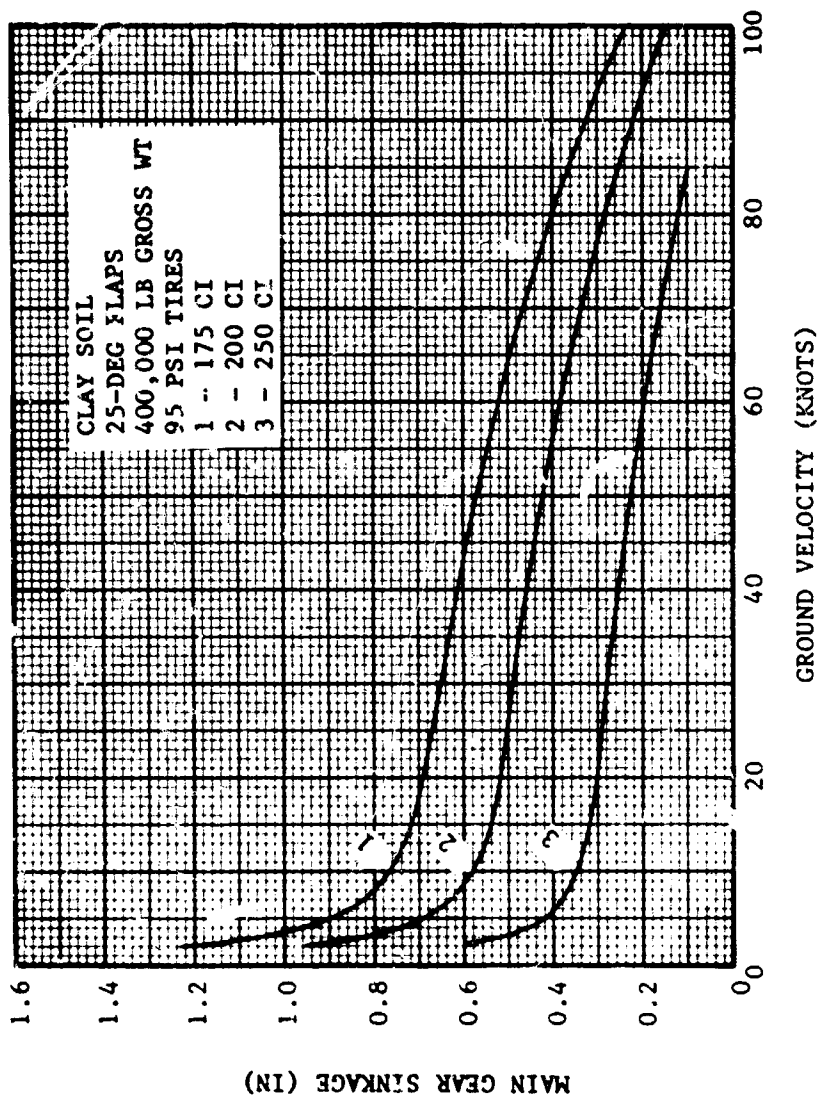


Figure 70 Soil Sinkage as a Function of Ground Velocity for C-5 at 400,000 Lb. Gross Weight

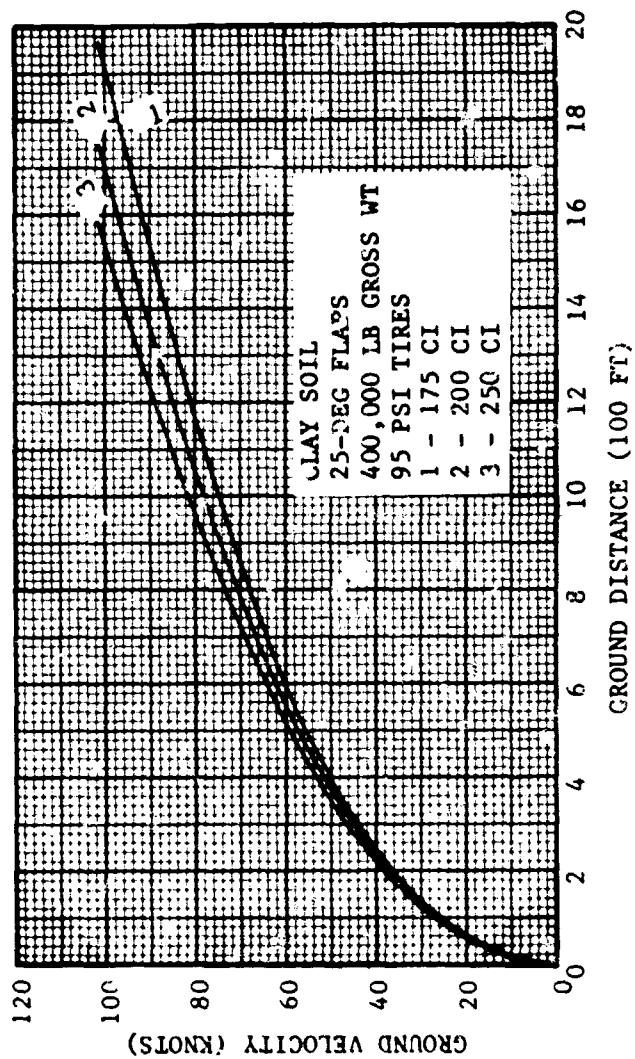


Figure 71. Airplane Velocity as a Function of Ground Distance for C-5 at 400,000 lb. Gross Weight

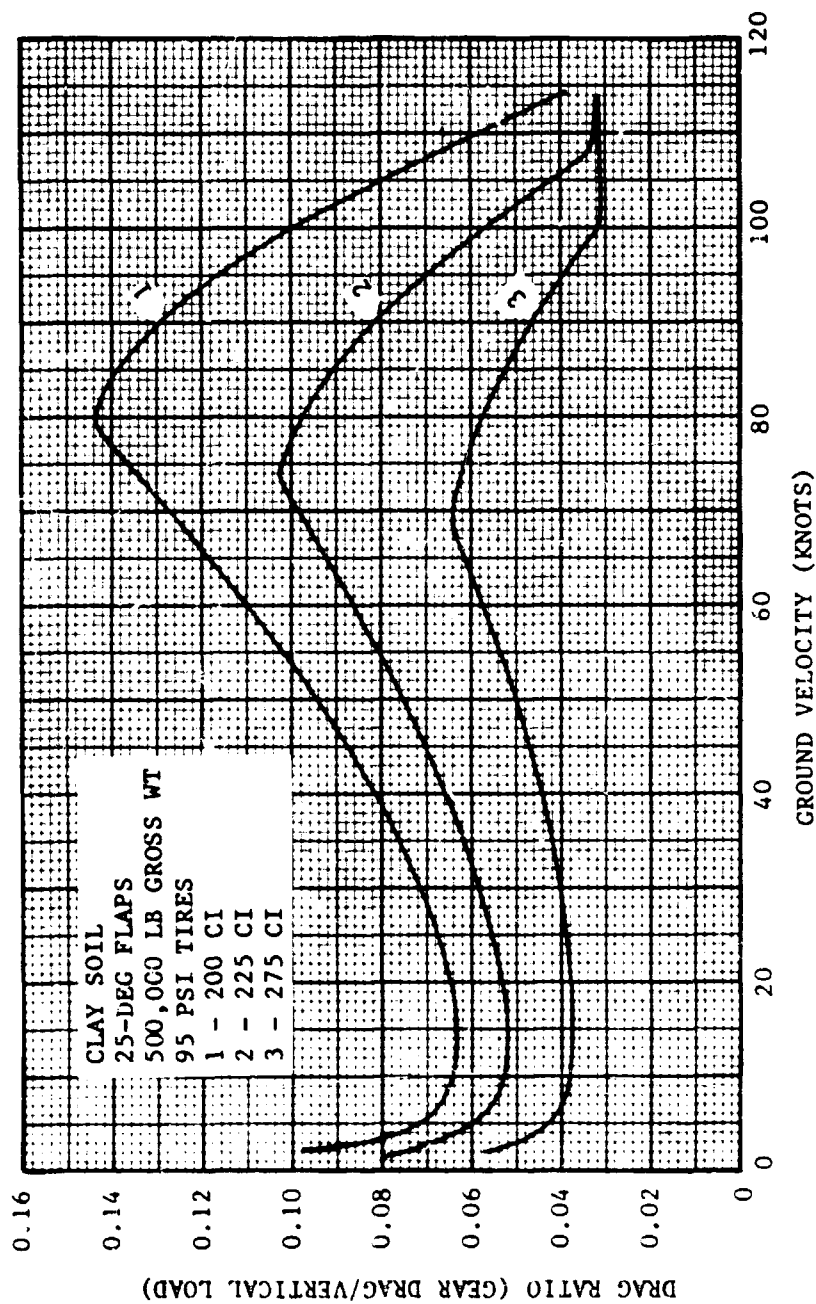


Figure 72 Drag Ratio as a Function of Ground Velocity for C-5 at 500,000 lb. Gross Weight

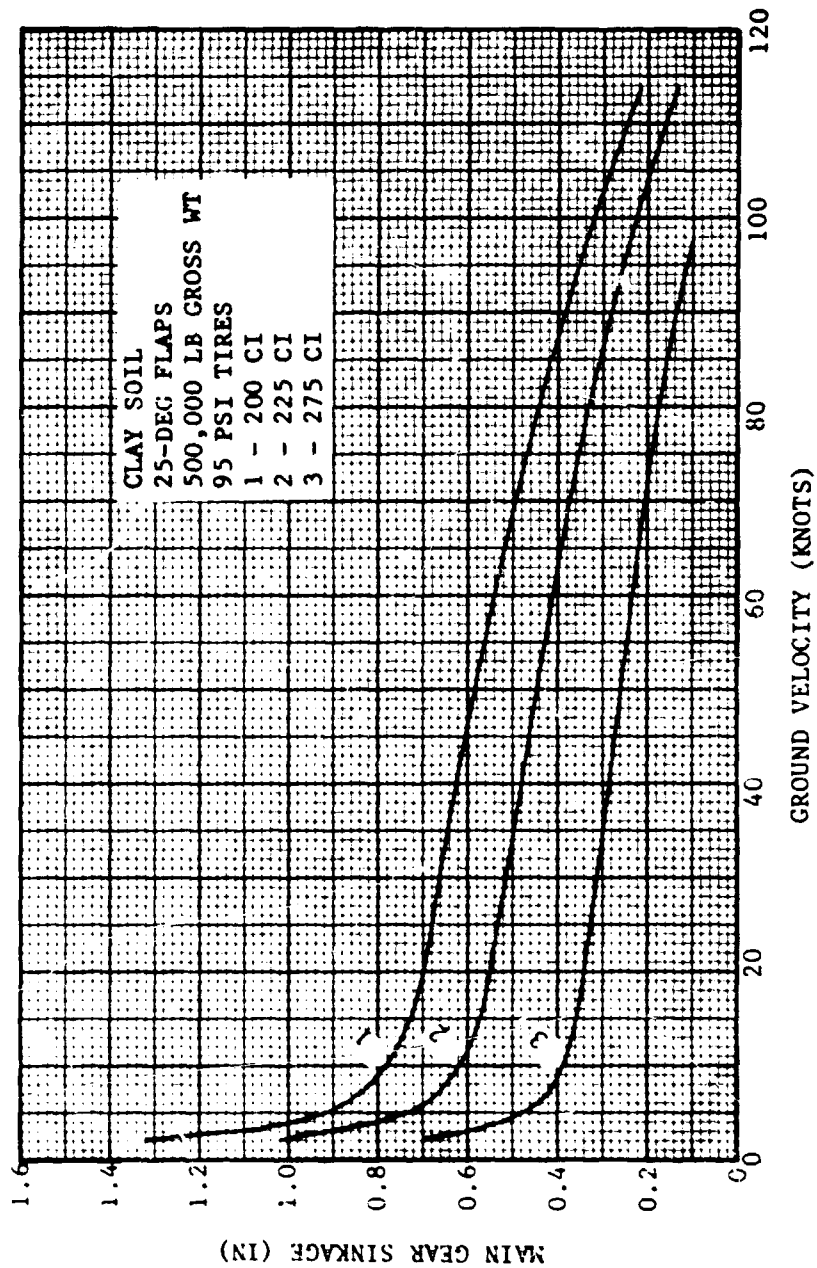


Figure 73 Soil Sinkage as a Function of Ground Velocity for C-5 at 500,000 Lb. Gross Weight

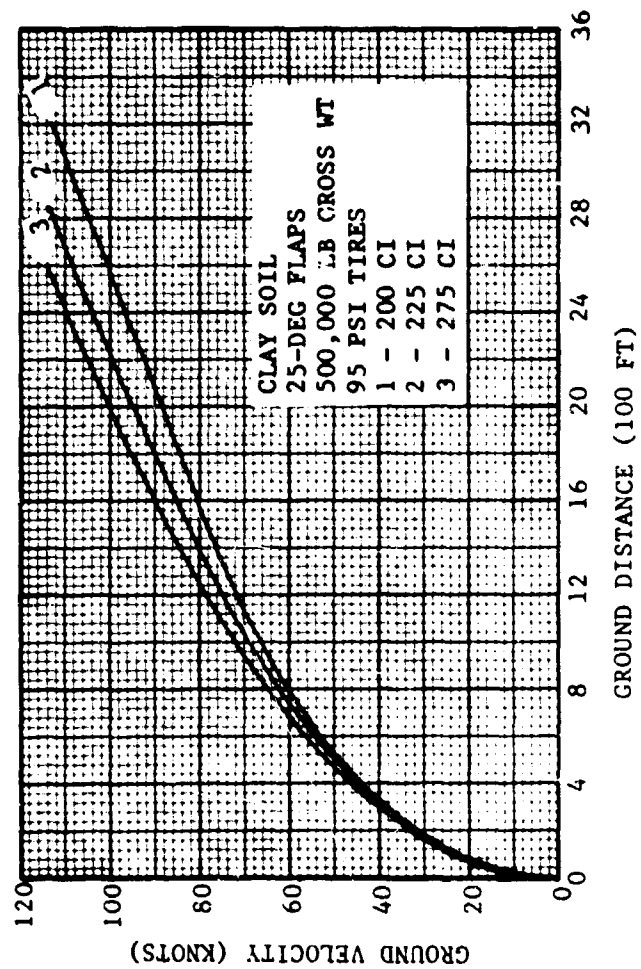


Figure 74. Airplane Velocity as a Function of Ground Distance for C-5 at 500,000 lb. Gross Weight

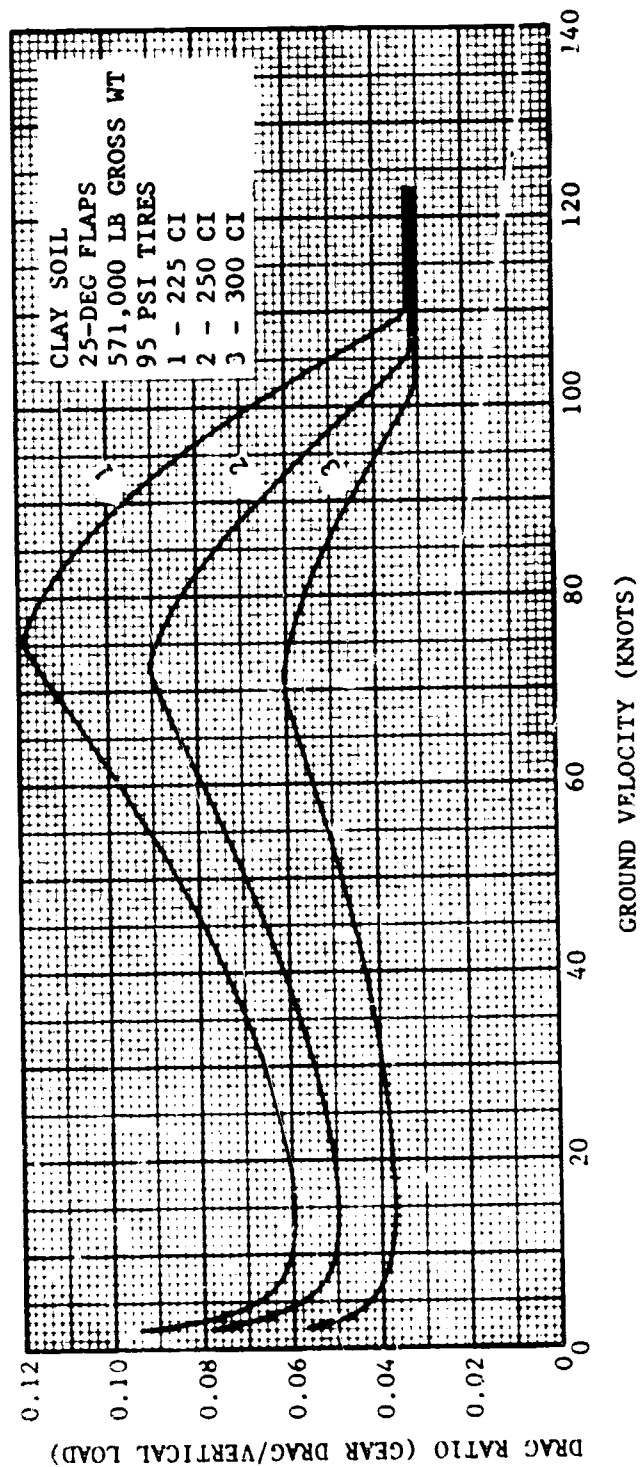


Figure 75 Drag Ratio as a Function of Ground Velocity for C-5 at 571,000 Lb. Gross Weight

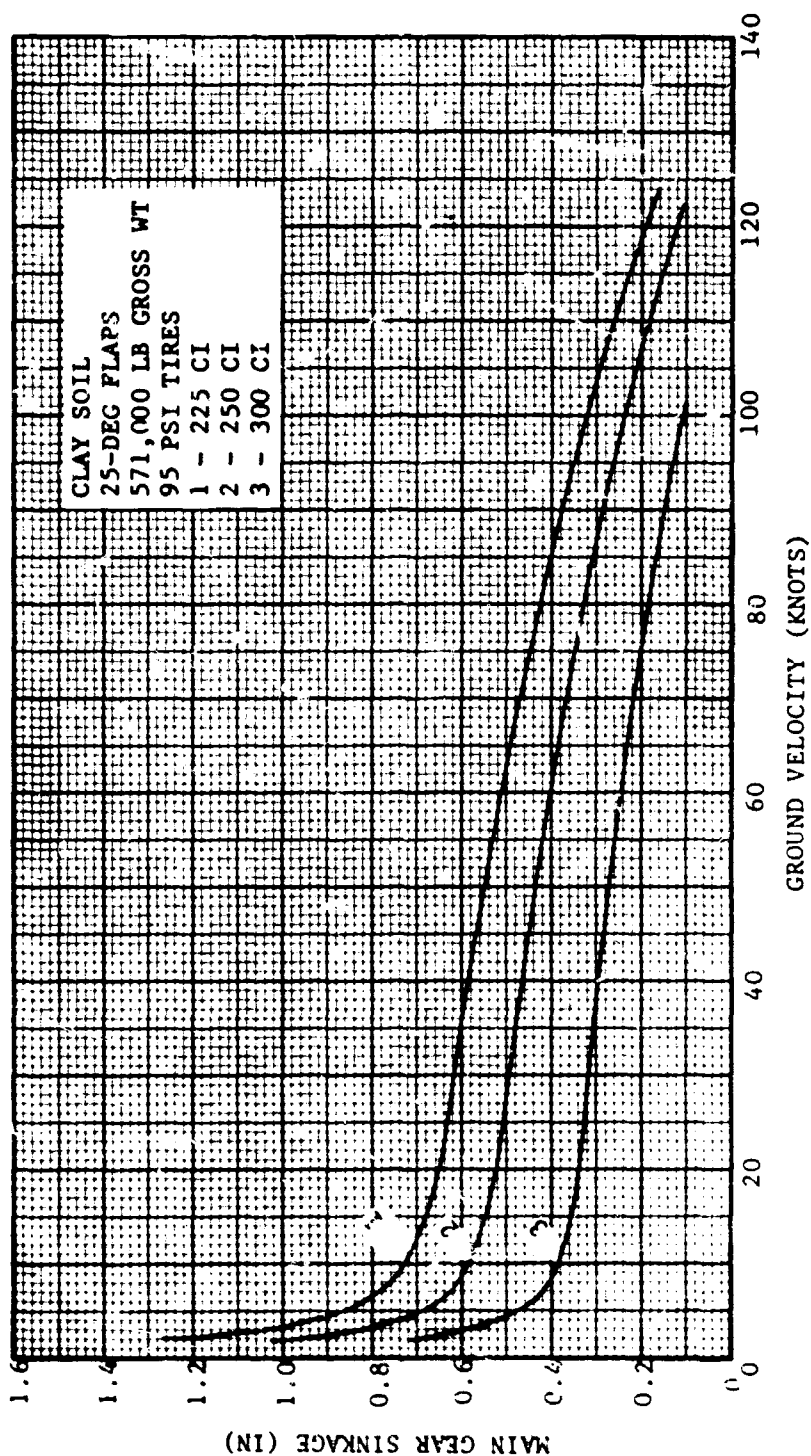


Figure 76 Soil Sinkage as a Function of Ground Velocity for C-5 at 571,000 Lb. Gross Weight

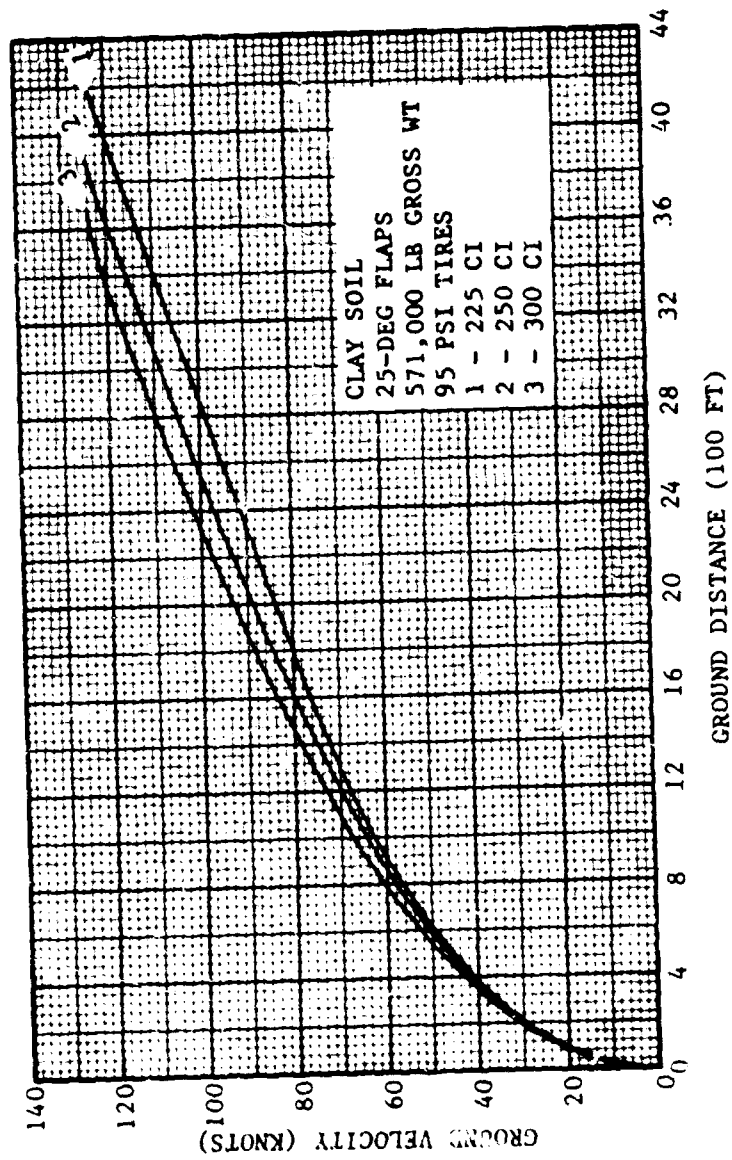


Figure 77. Airplane Velocity as a Function of Ground Distance  
for C-5 at 571,000 lb. Gross Weight

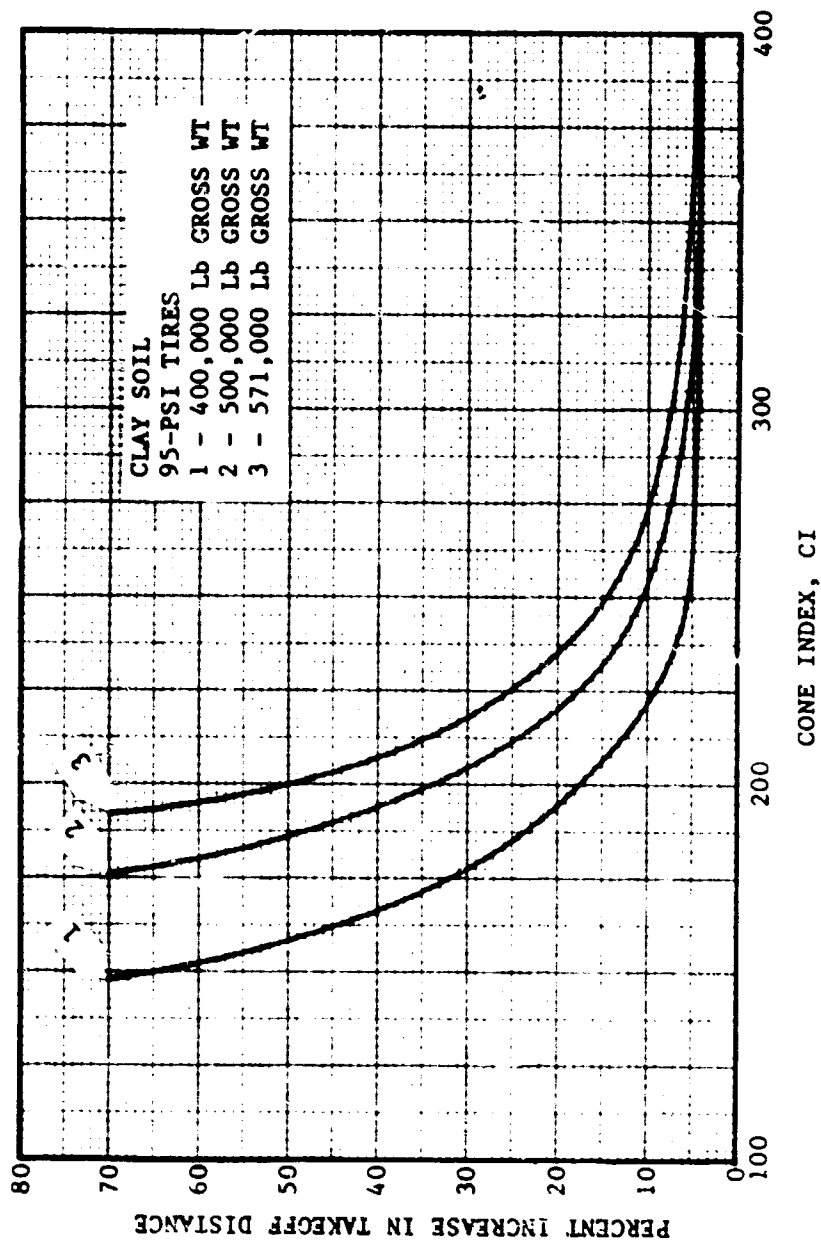


Figure 78 Percent Increase in Takeoff Distance Over Paved Surface for C-5 Aircraft

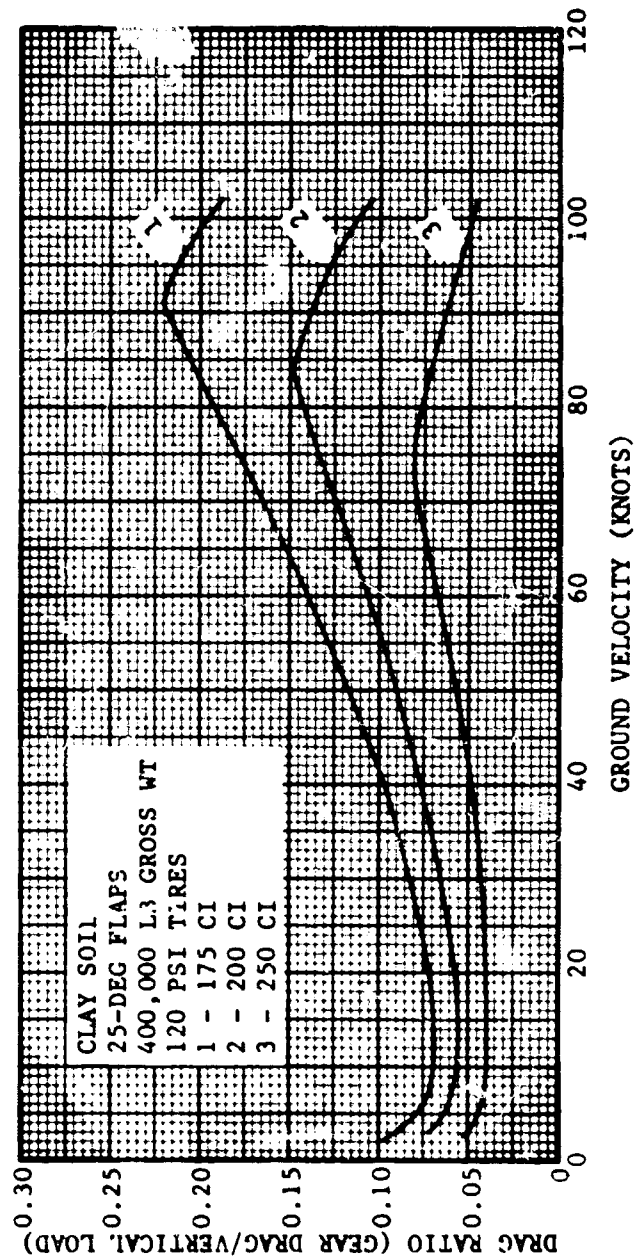


Figure 79 Drag Ratio as a Function of Ground Velocity for C-5 at 400,000 Lb. Gross Weight

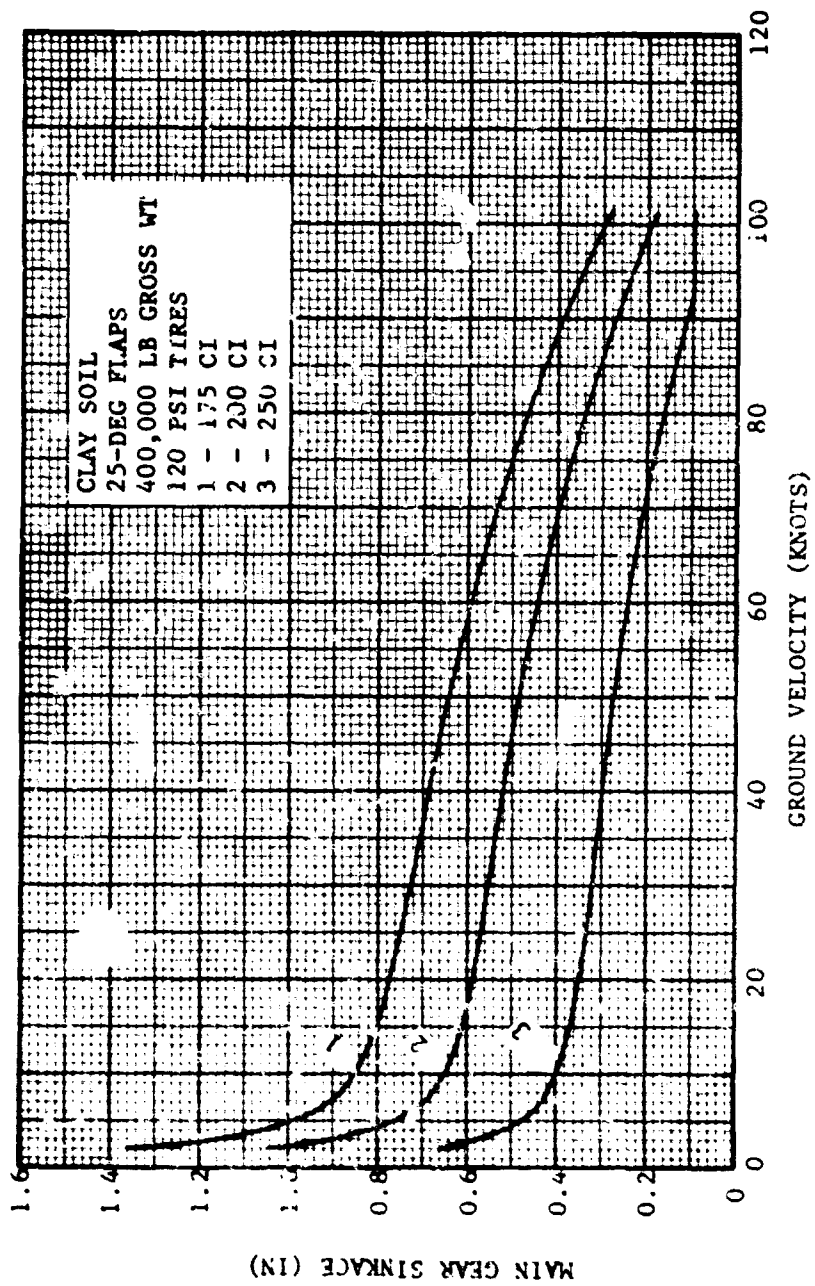


Figure 80 Soil Sinkage as a Function of Ground Velocity for C-5 at 400,000 Lb. Gross Weight

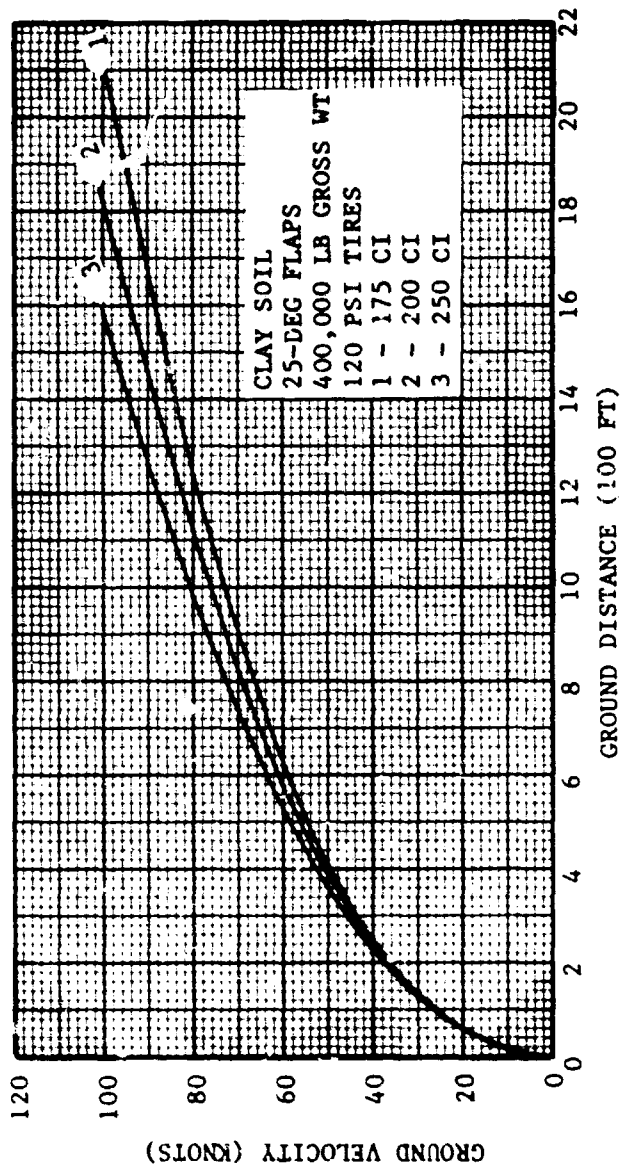


Figure 81. Airplane Velocity as a Function of Ground Distance for C-5 at 400,000 lb. Gross Weight

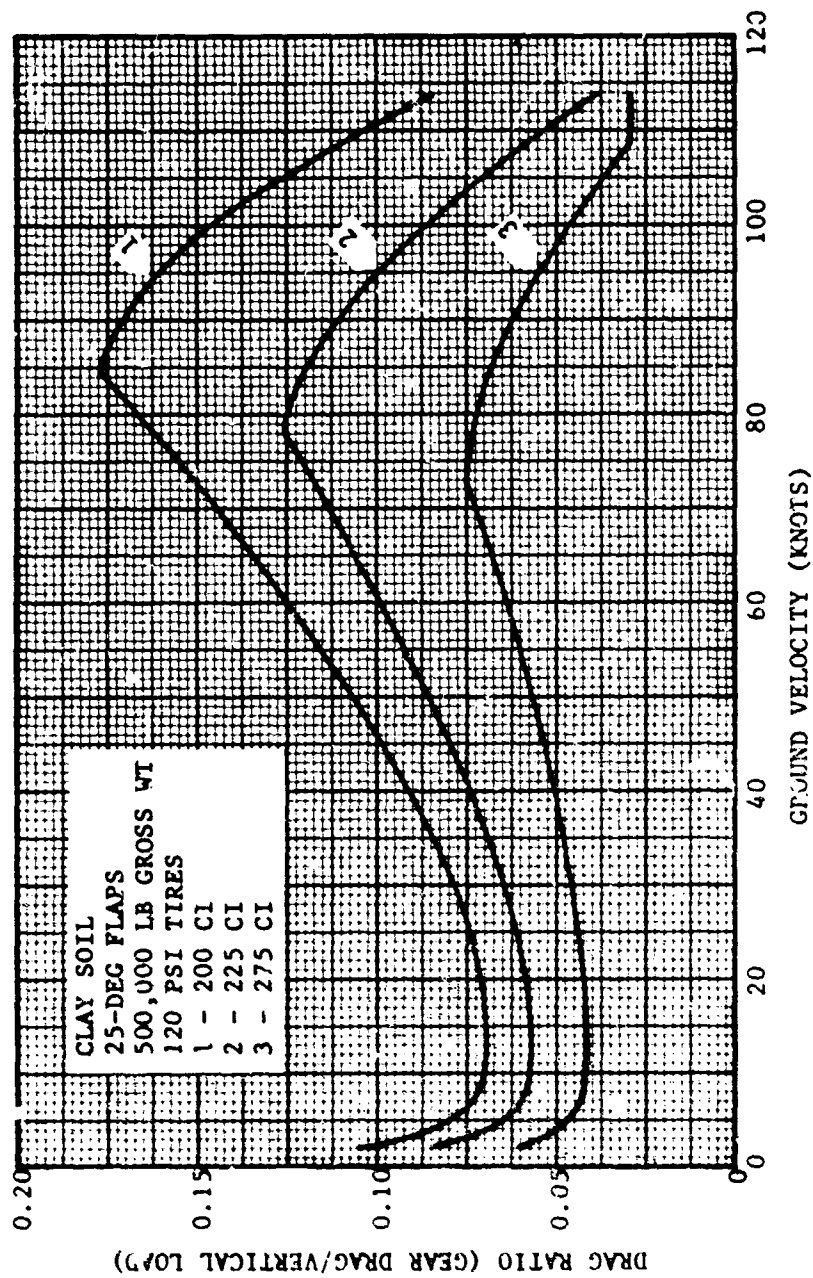


Figure 82 Drag Ratio as a Function of Ground Velocity for  
C-5 at 500,000 Lb. Gross Weight

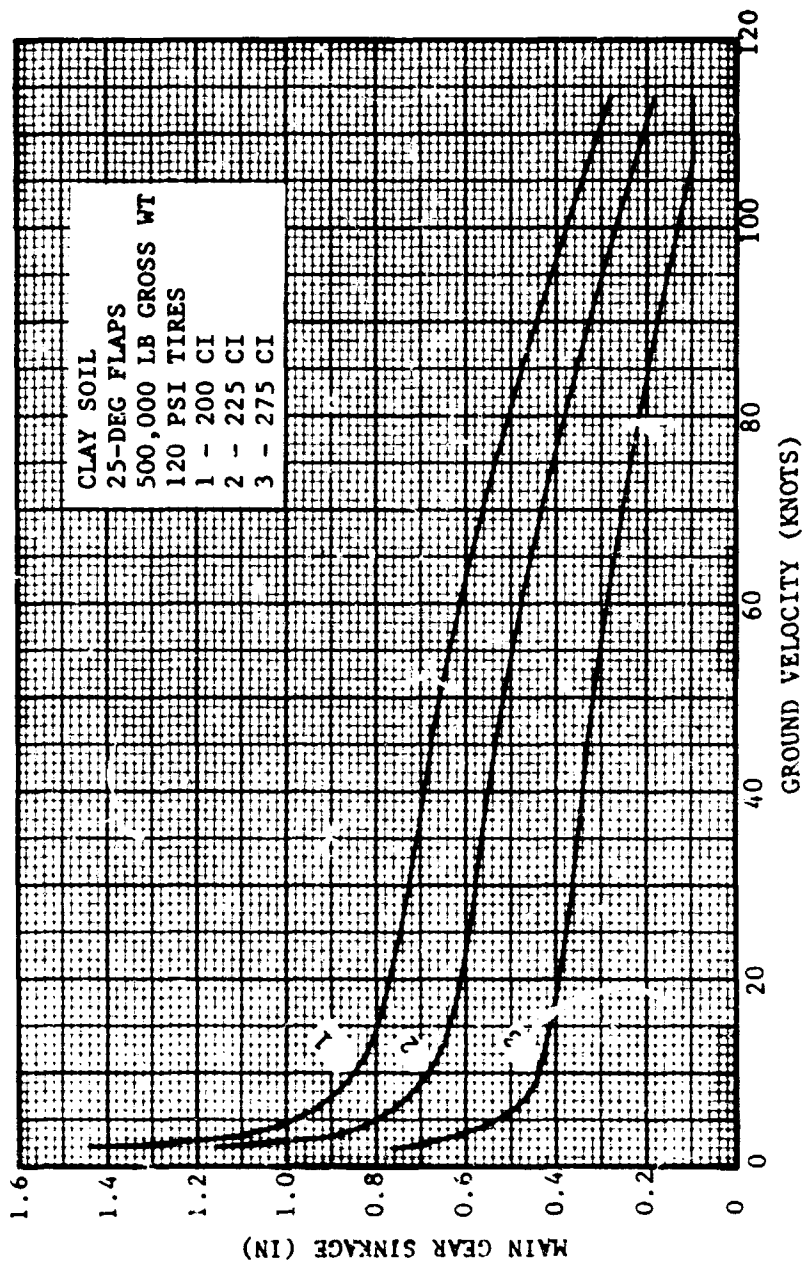


Figure 83 Soil Sinkage as a Function of Ground Velocity  
for C-5 at 500,000 lb. Gross Weight

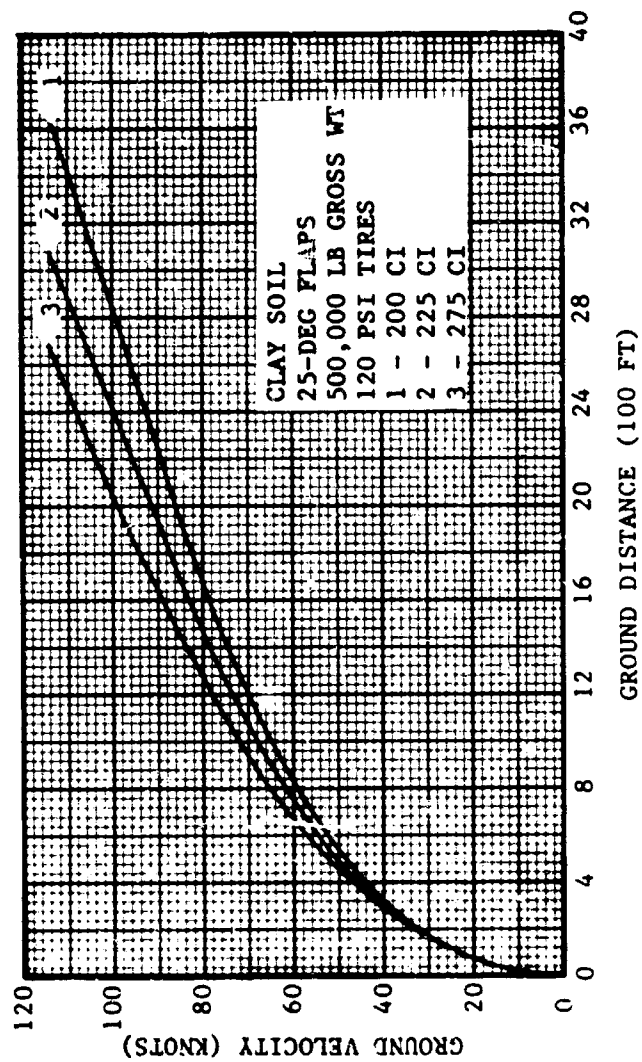


Figure 84. Airplane Velocity as a Function of Ground Distance for C-5 at 500,000 lb. Gross Weight

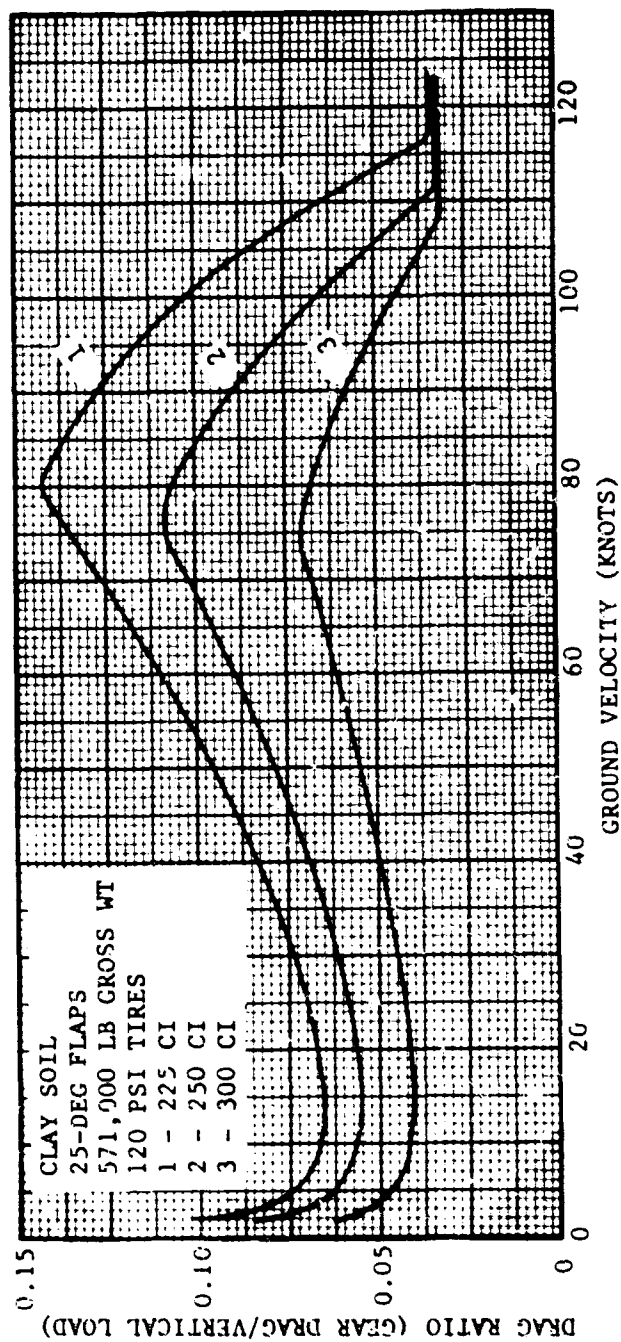


Figure 85 Drag Ratio as a Function of Ground Velocity  
for C-5 at 571,000 Lb. Gross Weight

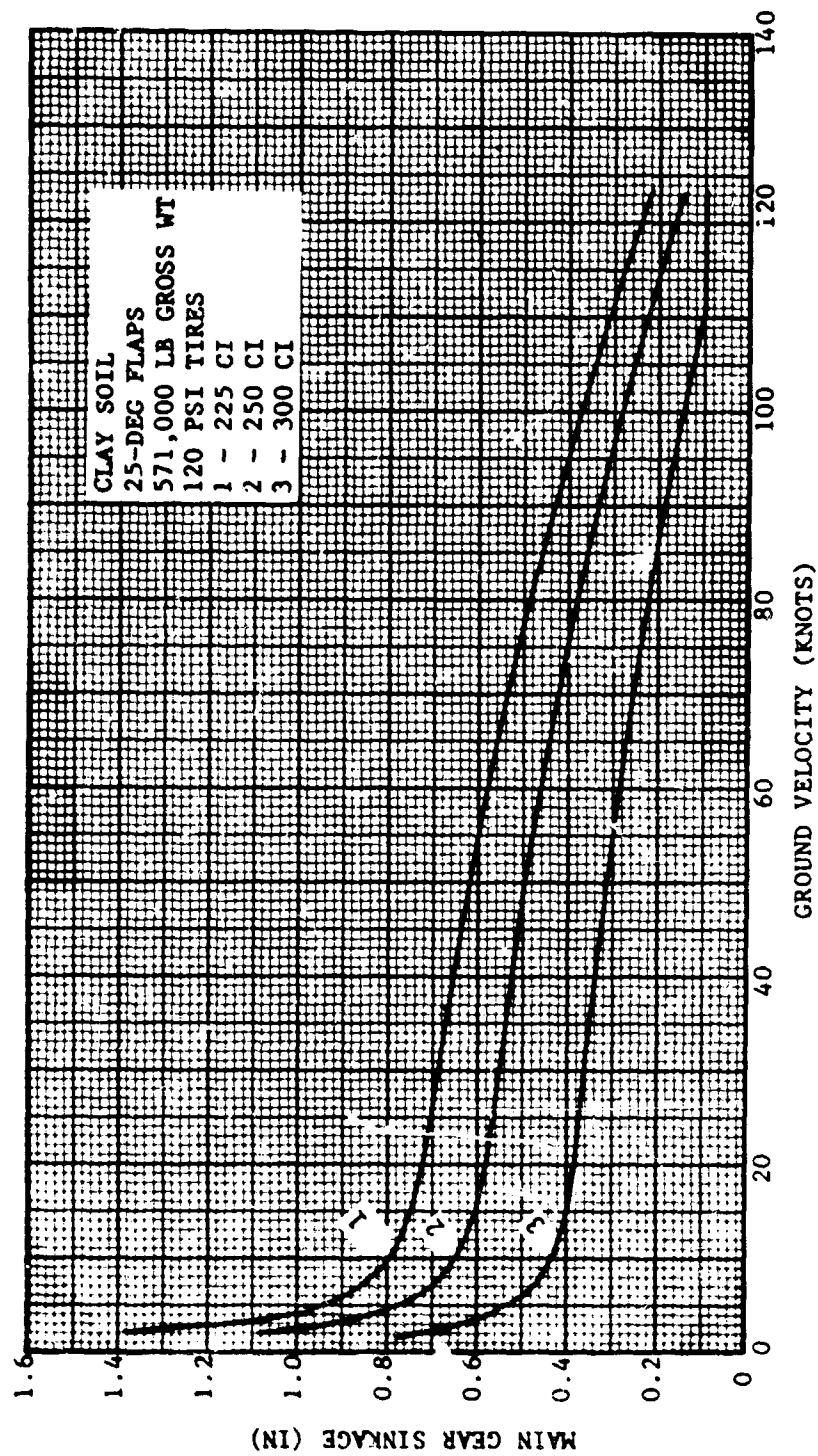


Figure 86 Soil Sinkage as a Function of Ground Velocity  
for C-5 at 571,000 Lb. Gross Weight

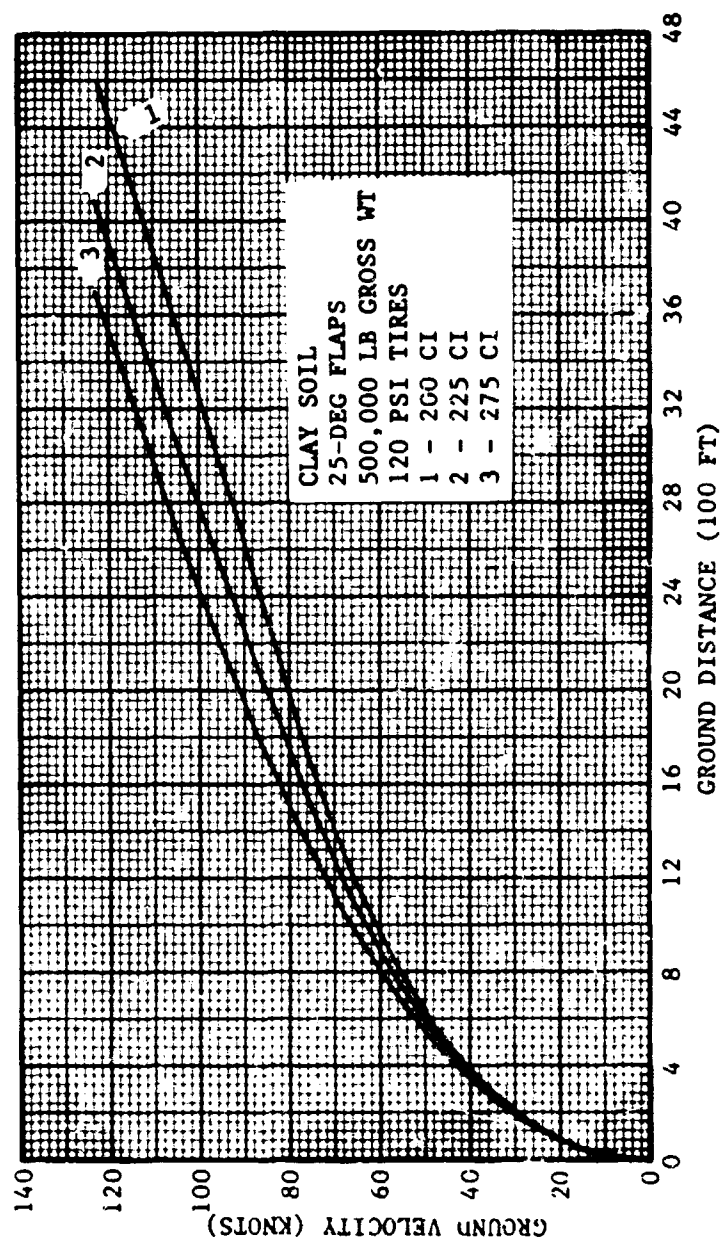


Figure 87. Airplane Velocity as a Function of Ground Distance for C-5 at 571,000 lb. Gross Weight

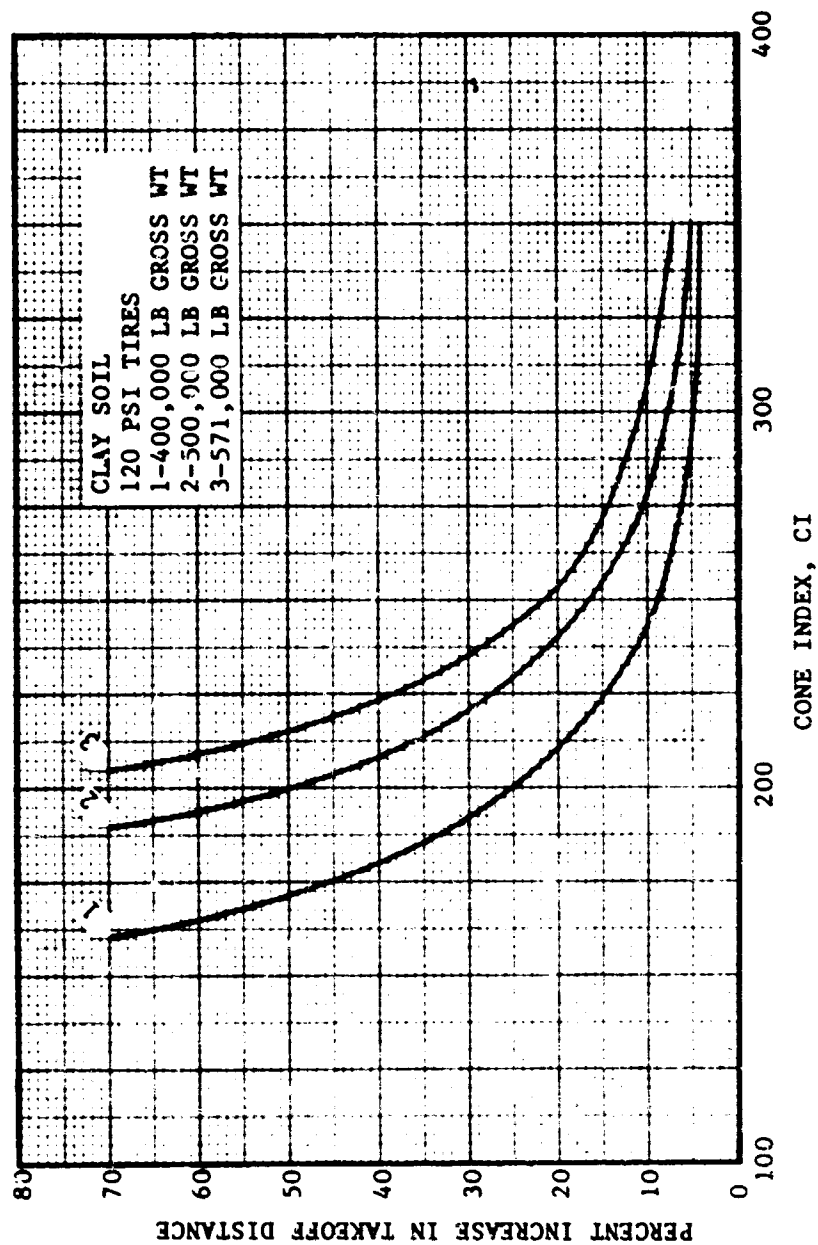


Figure 88 Percent Increase in Takeoff Distance Over Paved Surface for C-5 Aircraft

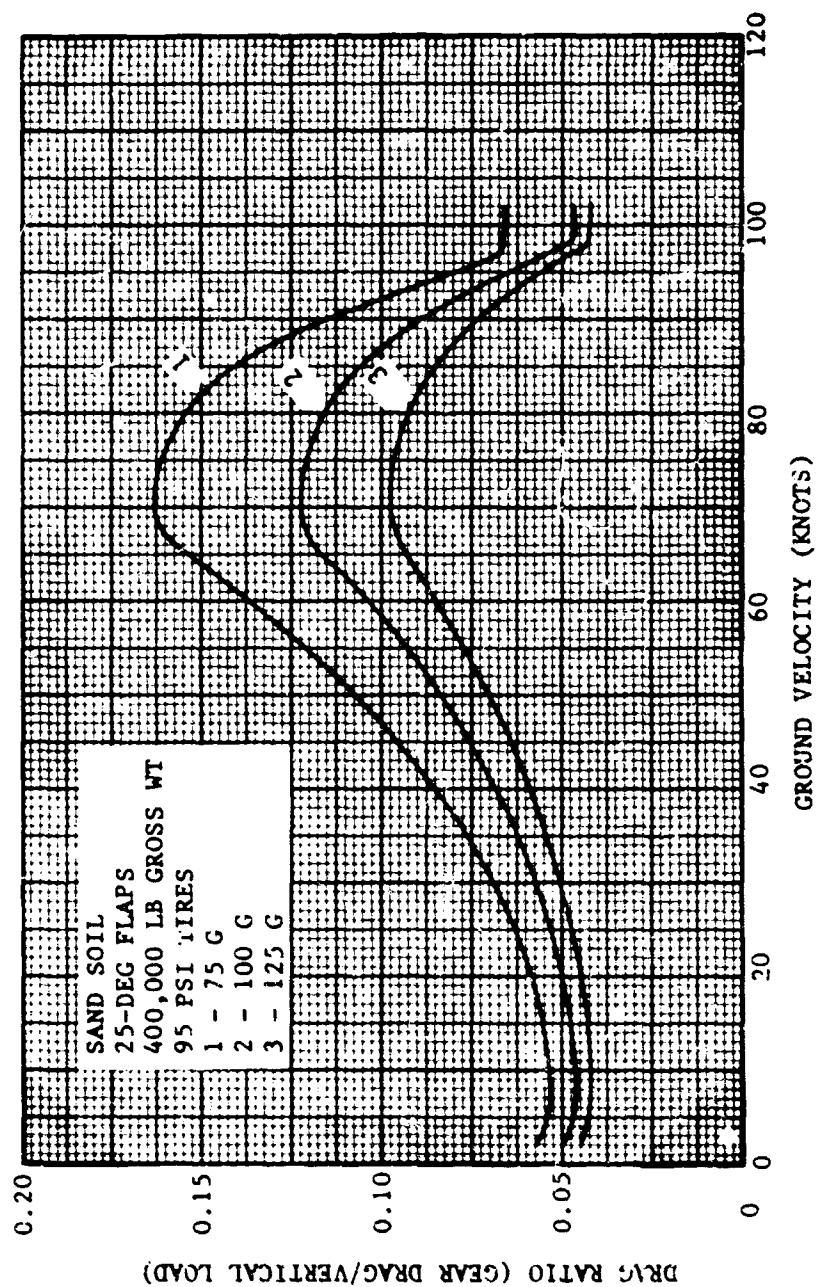


Figure 89 Drag Ratio as a Function of Ground Velocity for C-5 at 400,000 Lb. Gross Weight

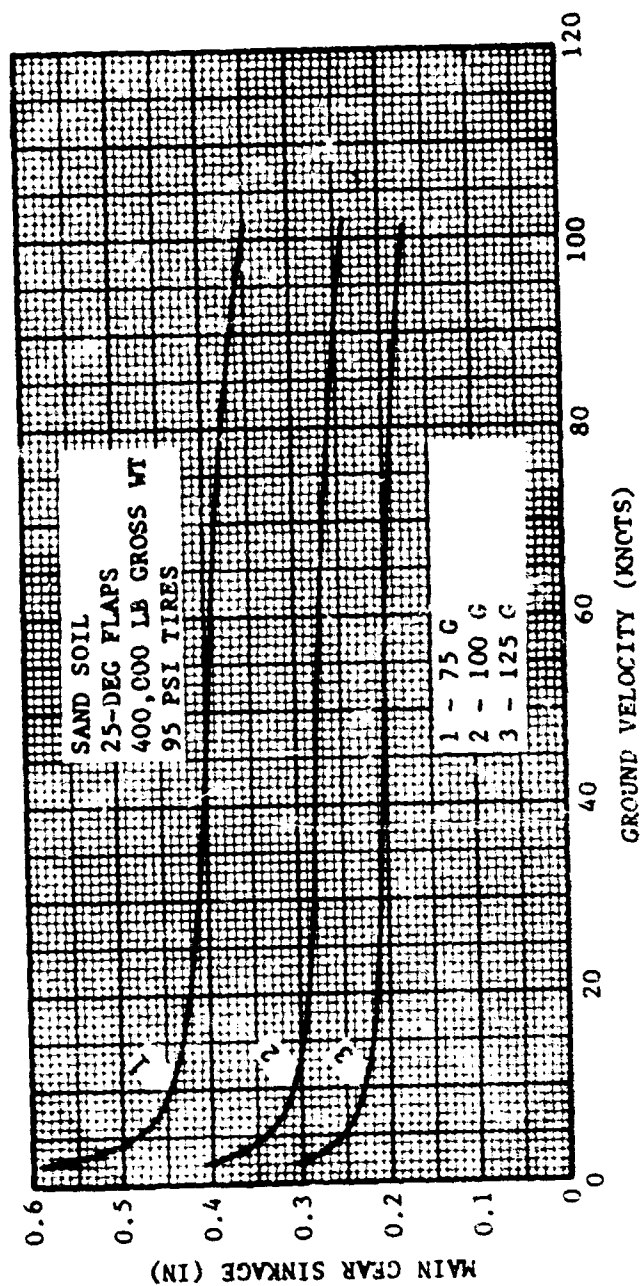


Figure 90 Soil Sinkage as a Function of Ground Velocity for C-5 at 400,000 Lb. Gross Weight

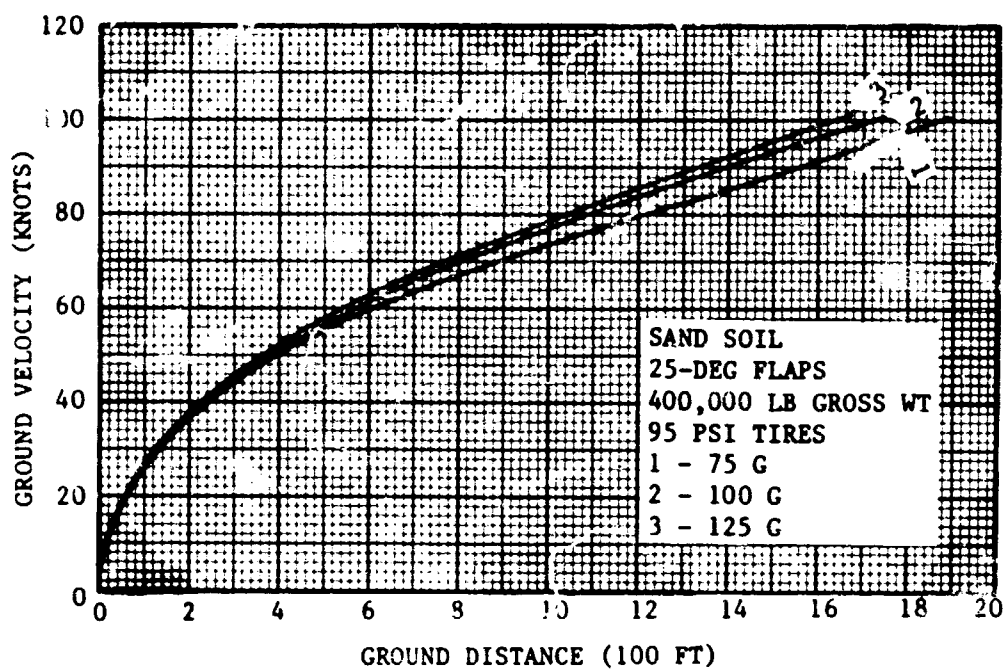


Figure 91. Airplane Velocity as a Function of Ground Distance for C-5 at 400,000 lb. Gross Weight

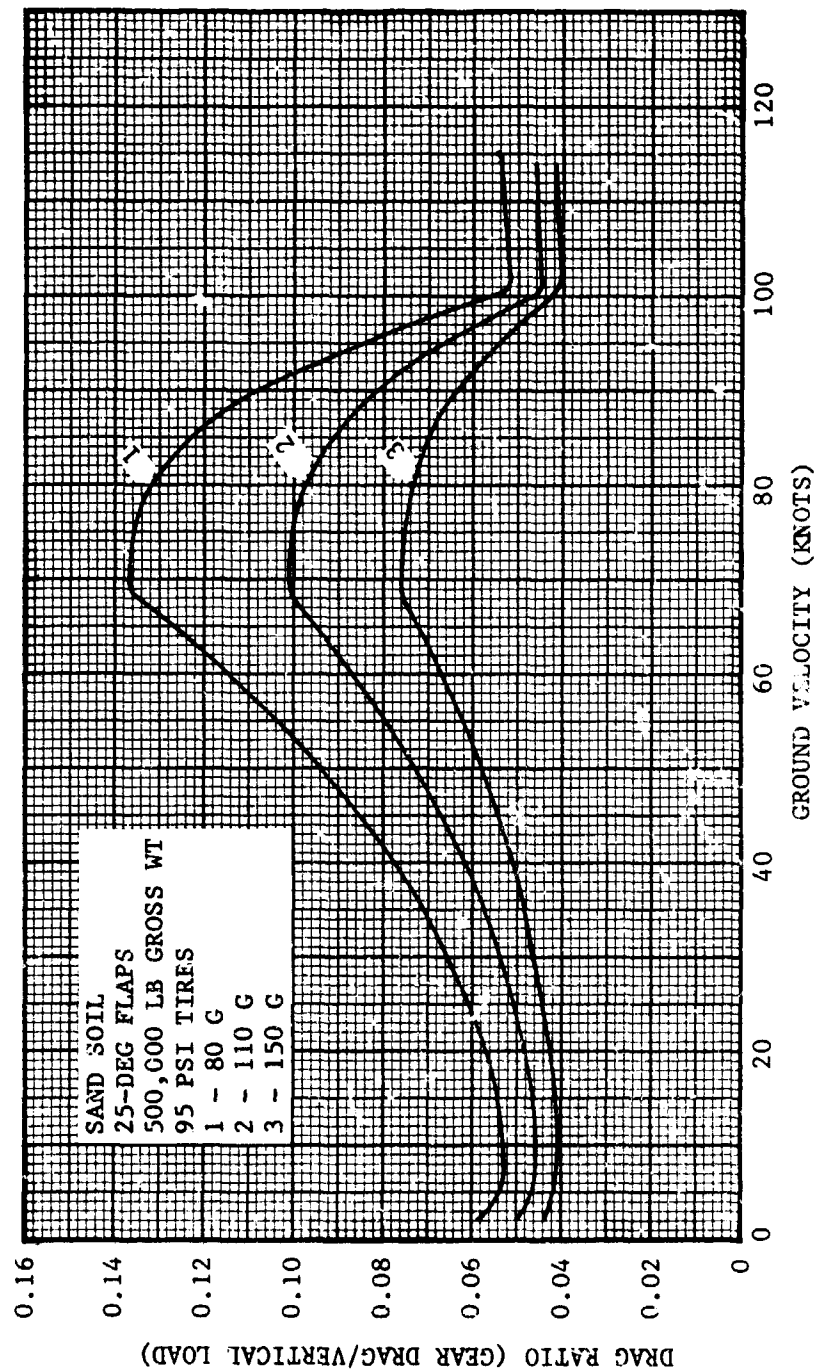


Figure 92 Drag Ratio as a Function of Ground Velocity for C-5 at 500,000 Lb. Gross Weight

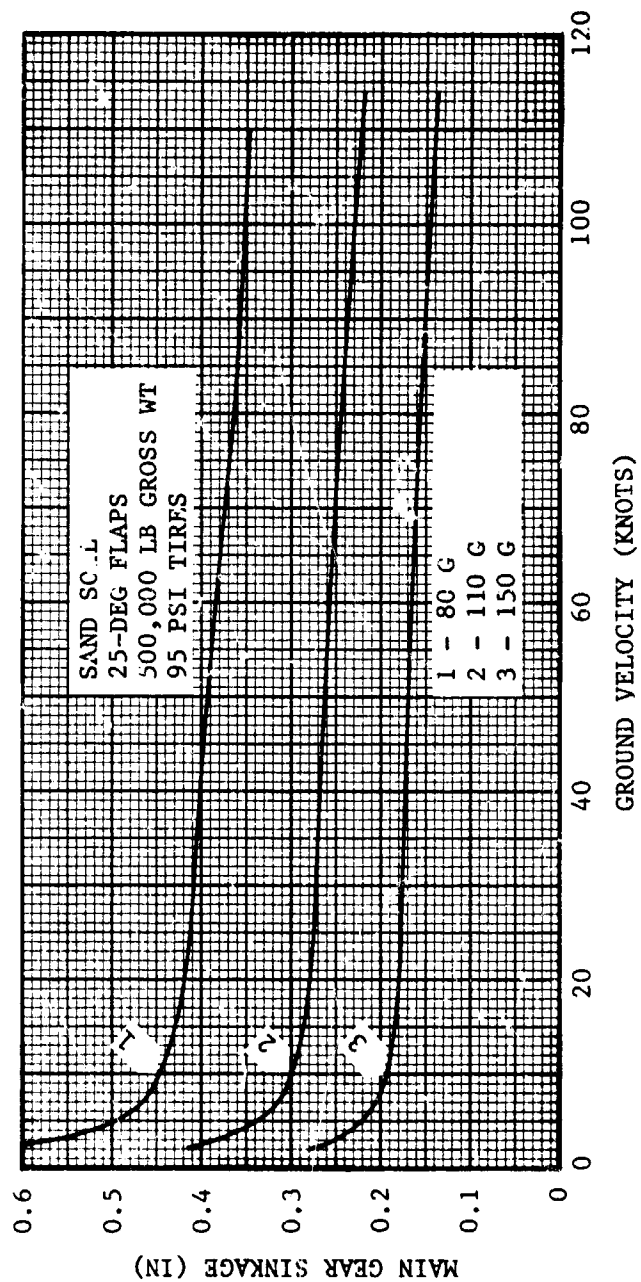


Figure 93 Soil Sinkage as a Function of Ground Velocity  
 for C-5 at 500,000 Lb. Gross Weight

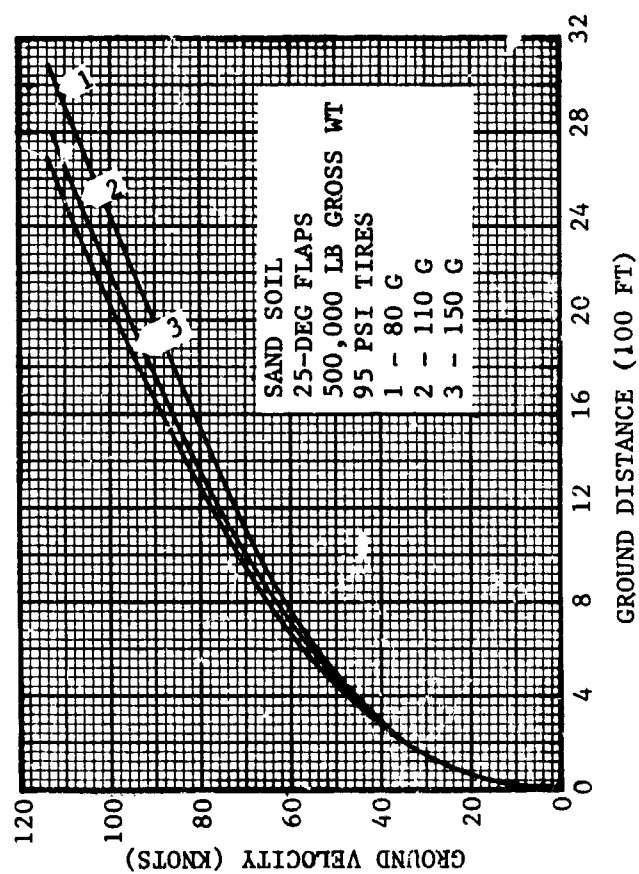


Figure 94. Airplane Velocity as a Function of Ground Distance for C-5 at 500,000 lb. Gross Weight

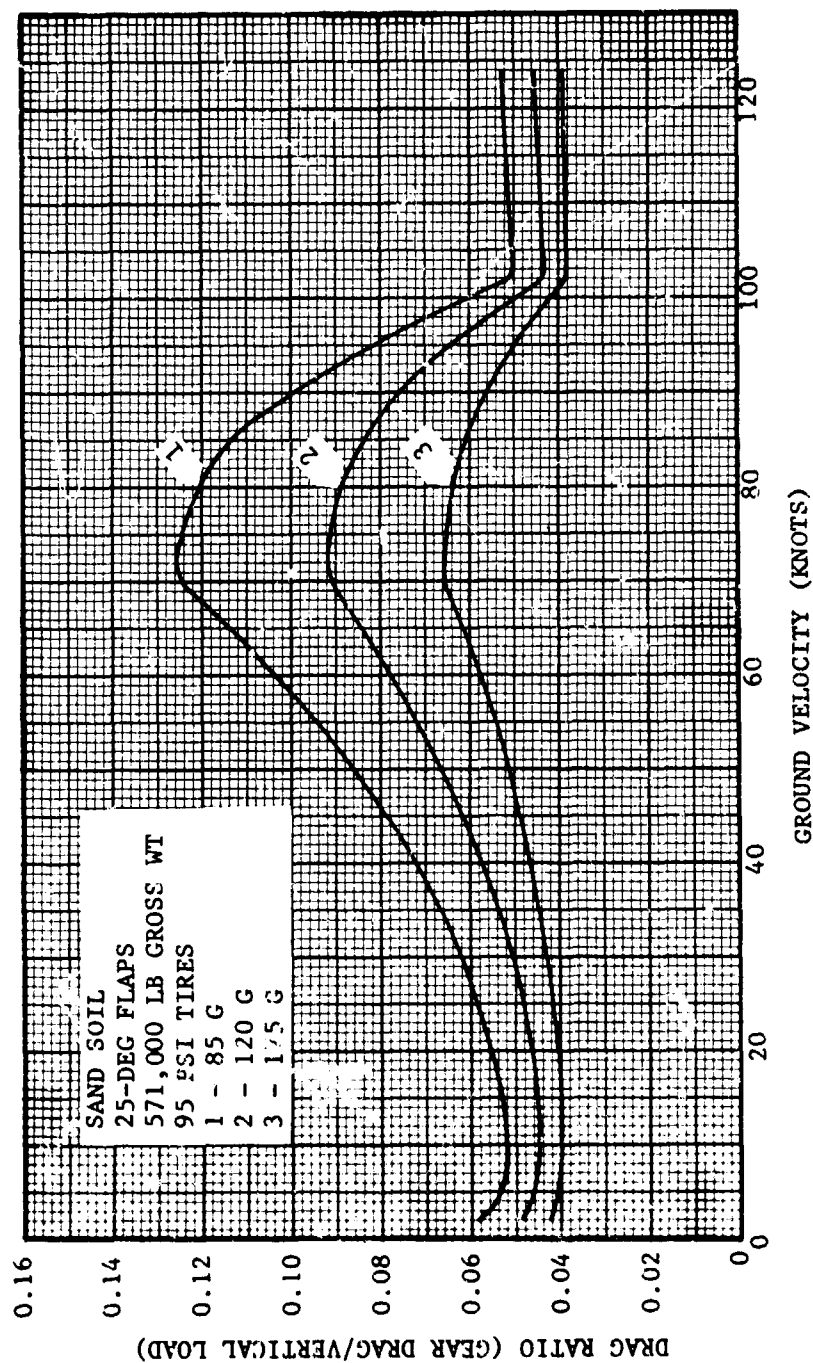


Figure 95 Drag Ratio as a Function of Ground Velocity  
for C-5 at 571,000 Lb. Gross Weight

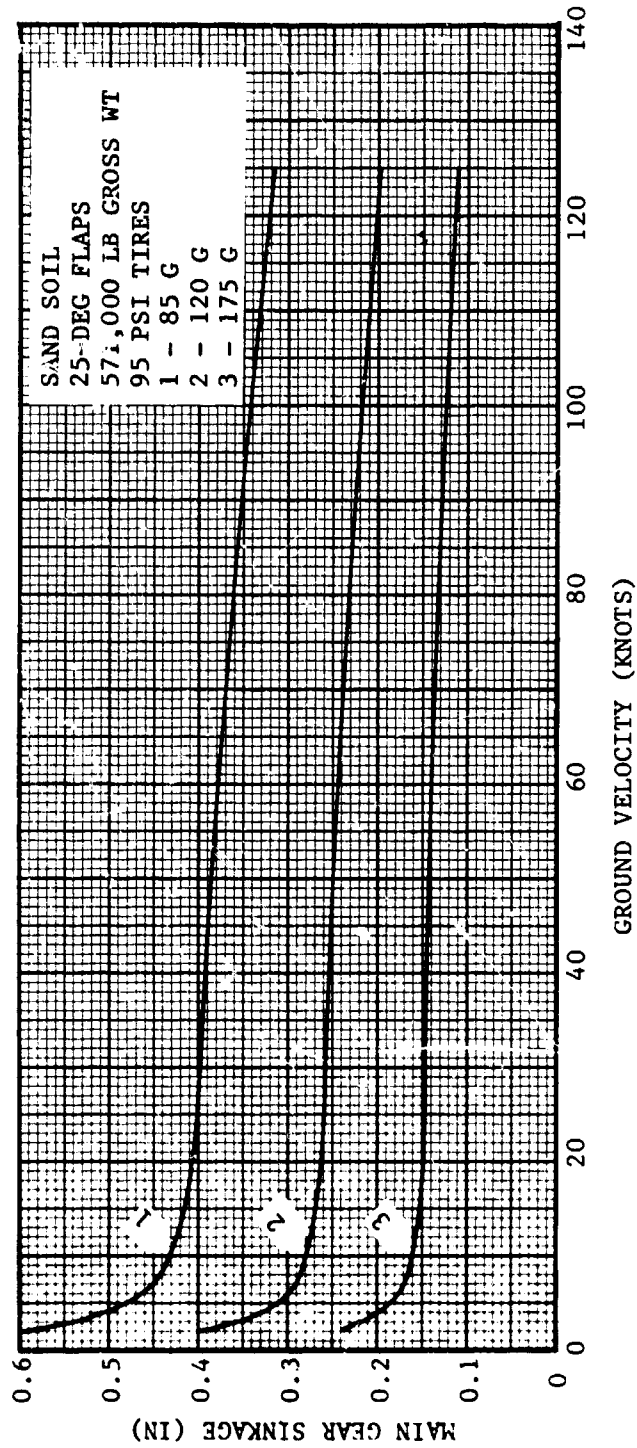


Figure 96 Soil Sinkage as a Function of Ground Velocity for C-5 at 571,000 Lb. Gross Weight

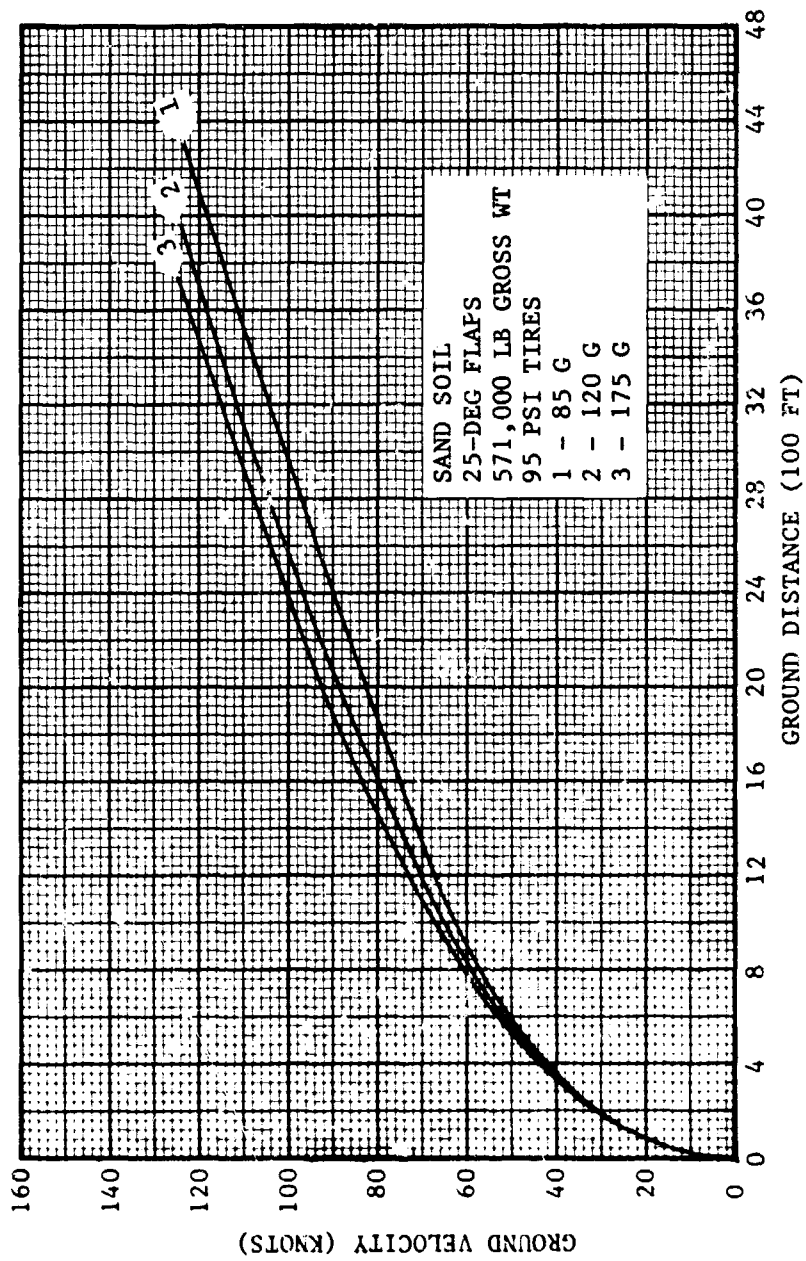


Figure 97. Airplane Velocity as a Function of Ground Distance for C-5 at 571,000 lb, Gross Weight

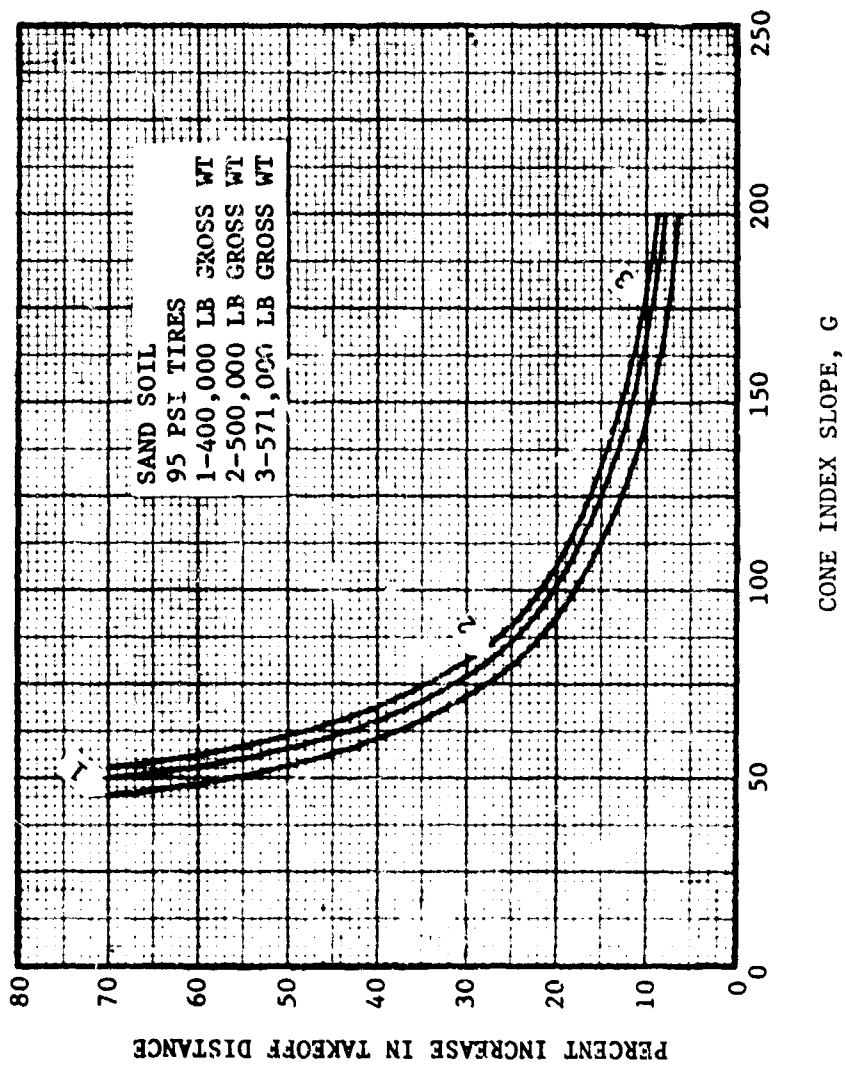


Figure 98 Percent Increase in Takeoff Distance Over Paved Surface for C-5 Aircraft

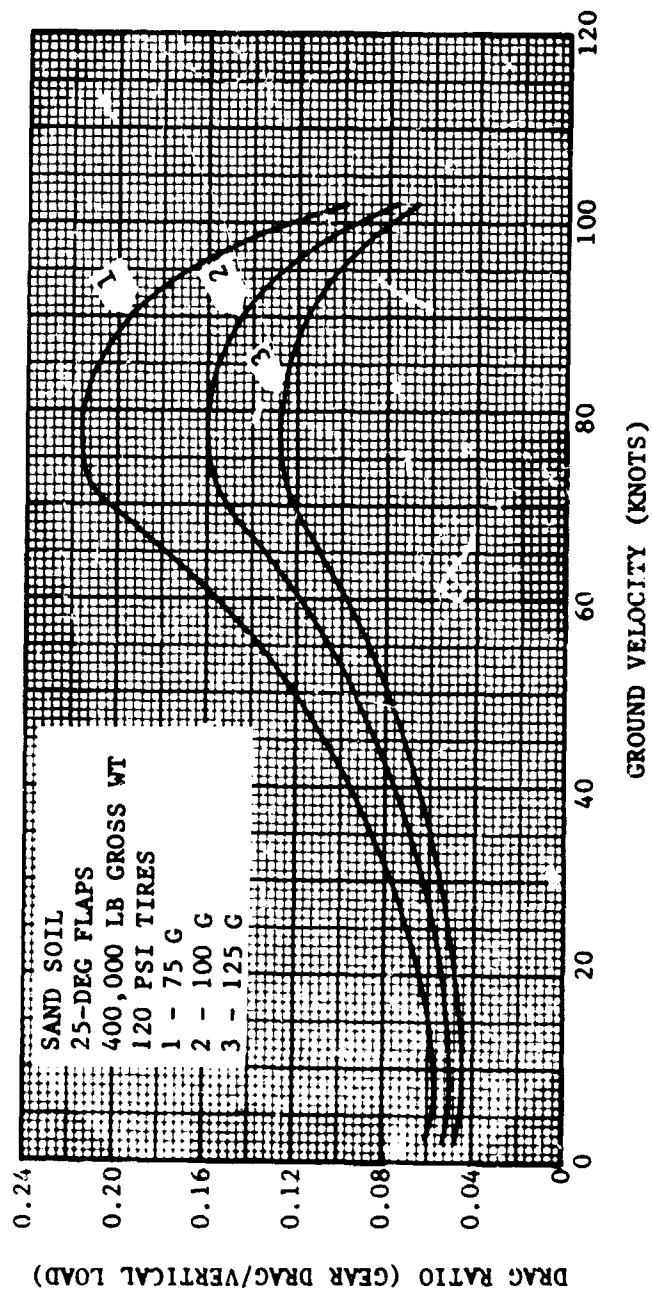


Figure 99 Drag Ratio as a Function of Ground Velocity for C-5 at 400,000 Lb. Gross Weight

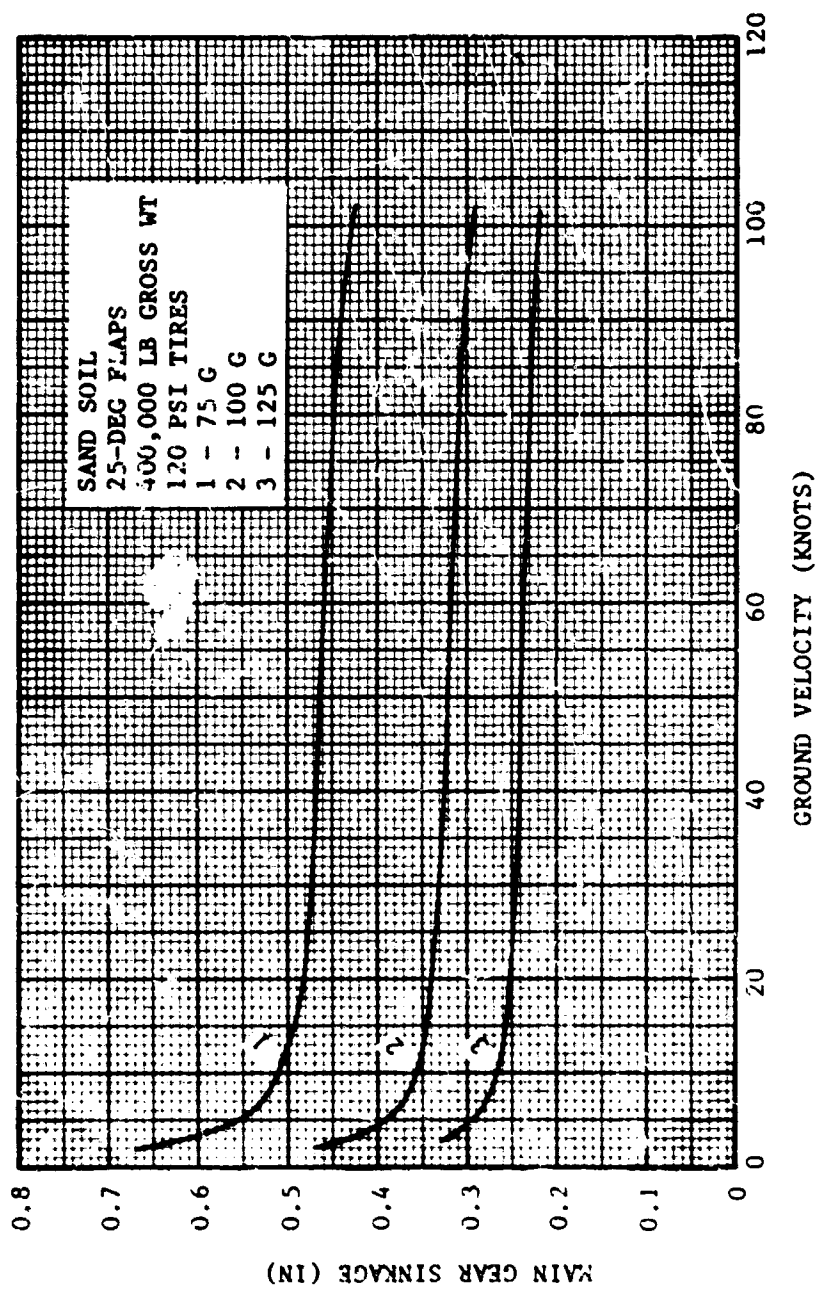


Figure 100 Soil Sinkage as a Function of Ground Velocity for C-5 at 400,000 Lb. Gross Weight

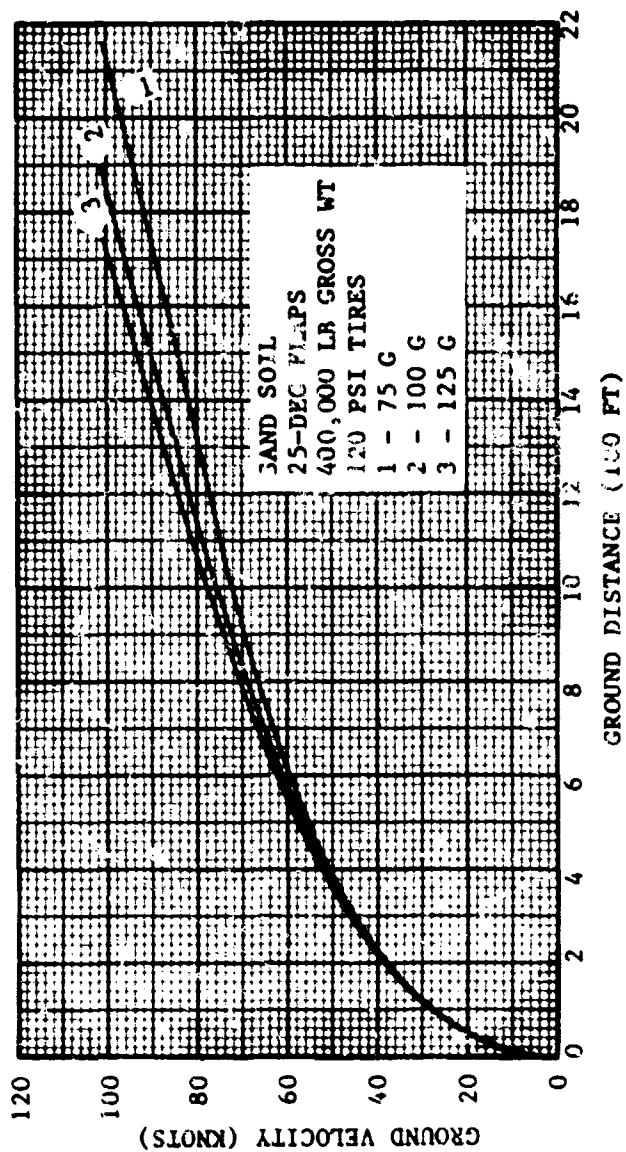


Figure 101. Airplane Velocity as a Function of Ground Distance for C-5 at 400,000 lb. Gross Weight

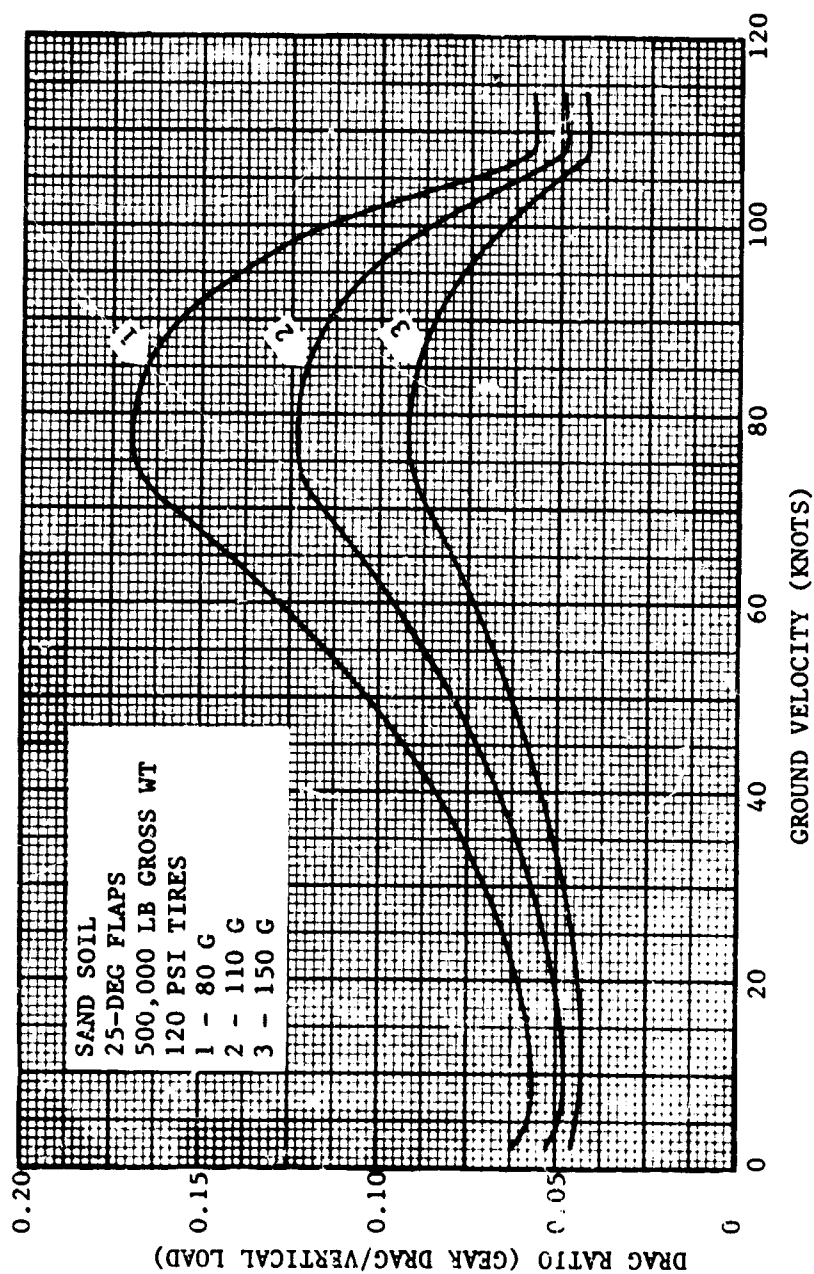


Figure 102 Drag Ratio as a Function of Ground Velocity for  
C-5 at 500,000 Lb. Gross Weight

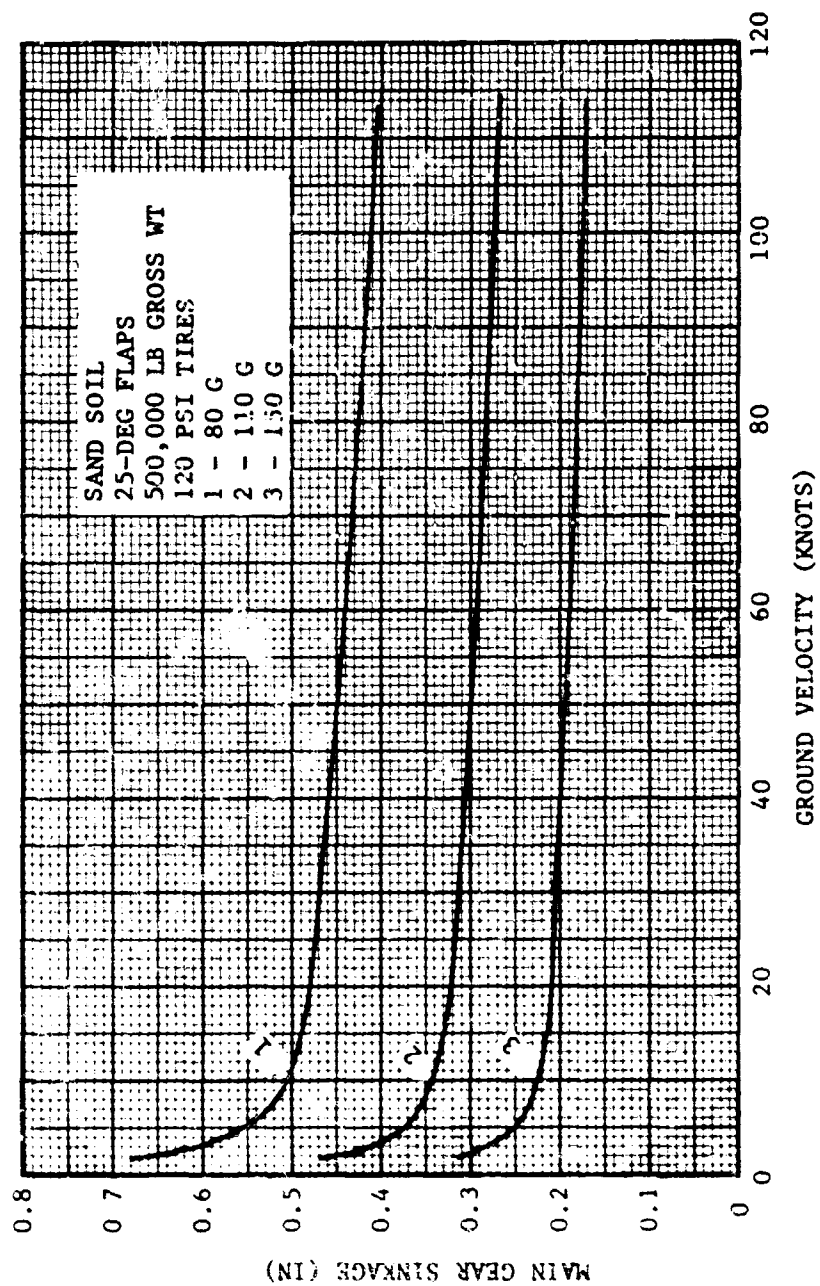


Figure 103 Soil Sinkage as a Function of Ground Velocity for C-5 at 500,000 lb. Gross Weight

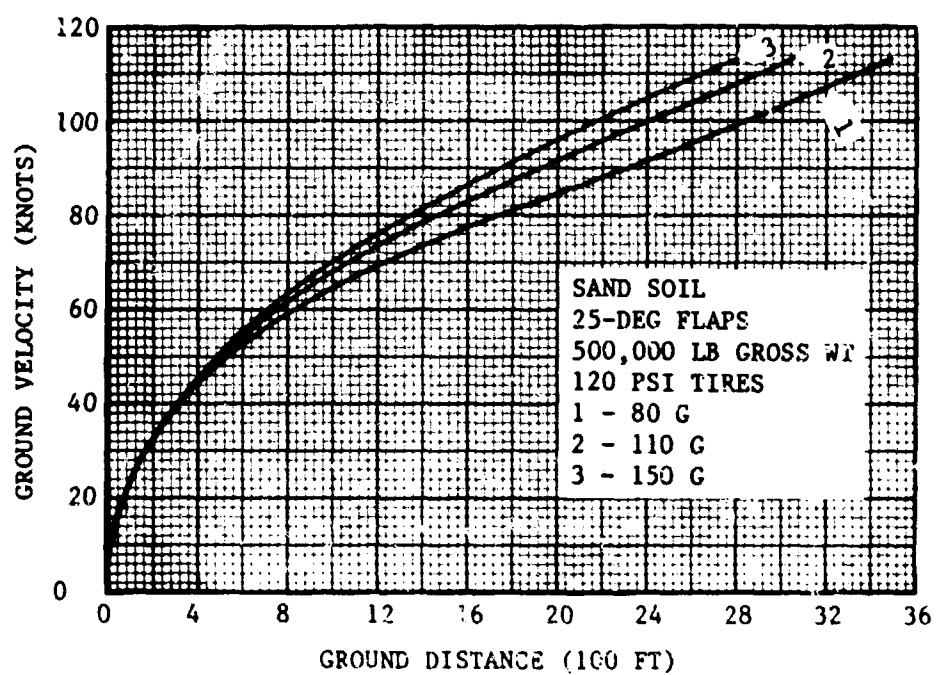


Figure 104. Airplane Velocity as a Function of Ground Distance for C-5 at 500,000 lb. Gross Weight

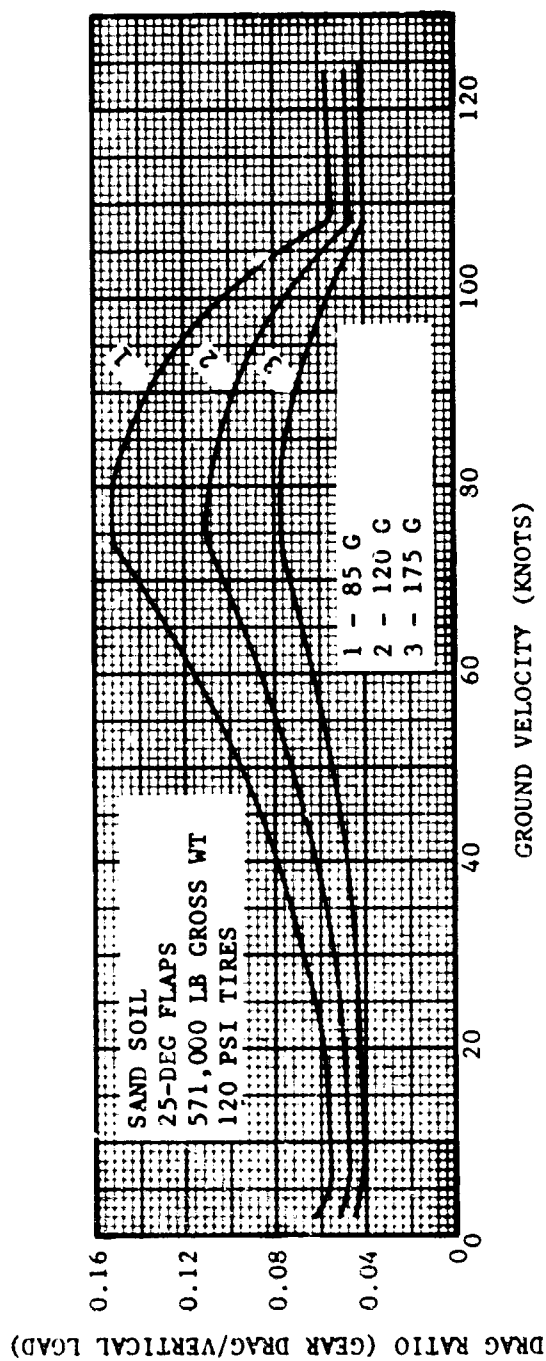


Figure 105 Drag Ratio as a Function of Ground Velocity for C-5 at 571,000 Lb. Gross Weight

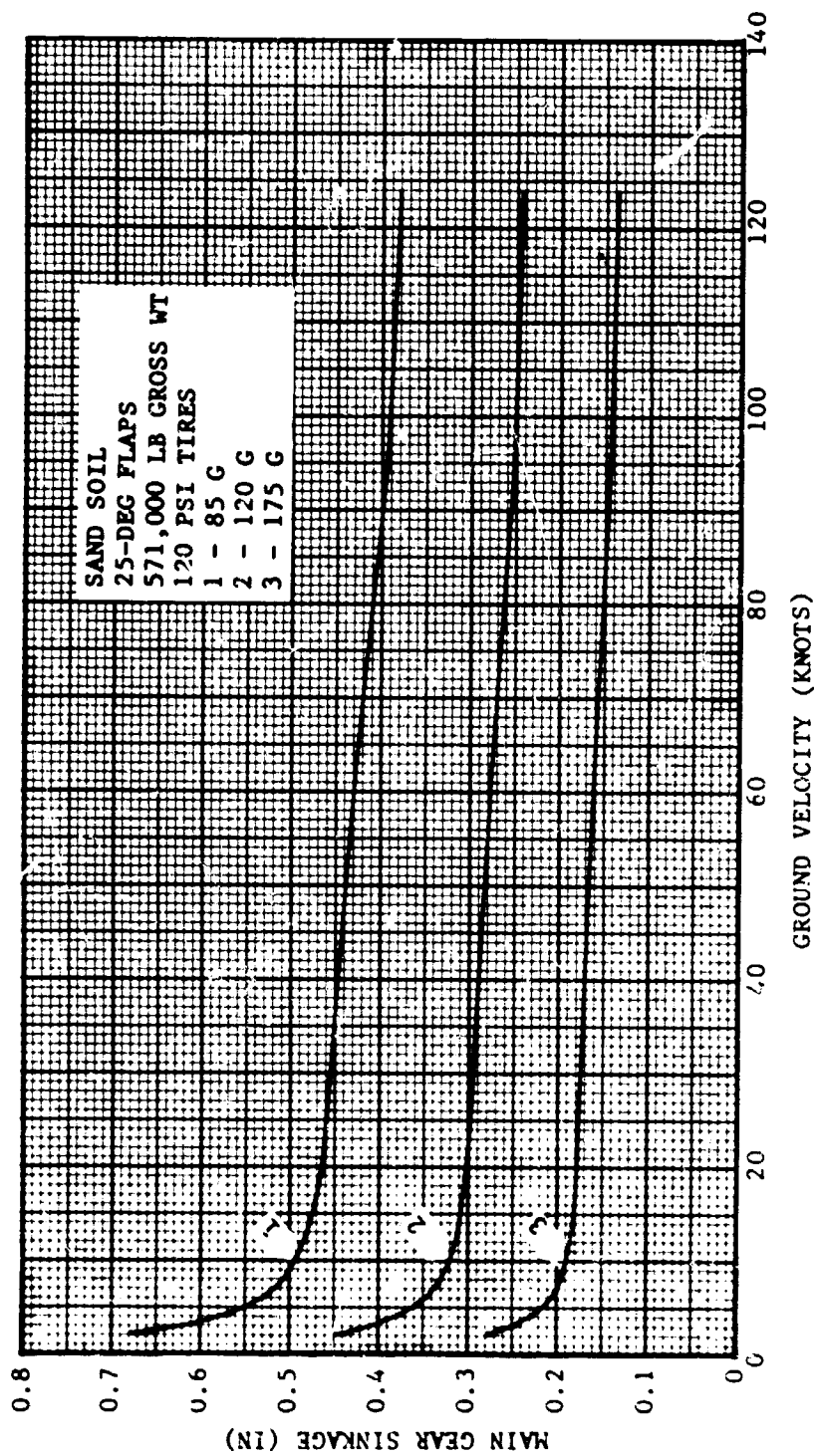


Figure 106 Soil Sinkage as a Function of Ground Velocity for C-5 at 571,000 Lb. Gross Weight

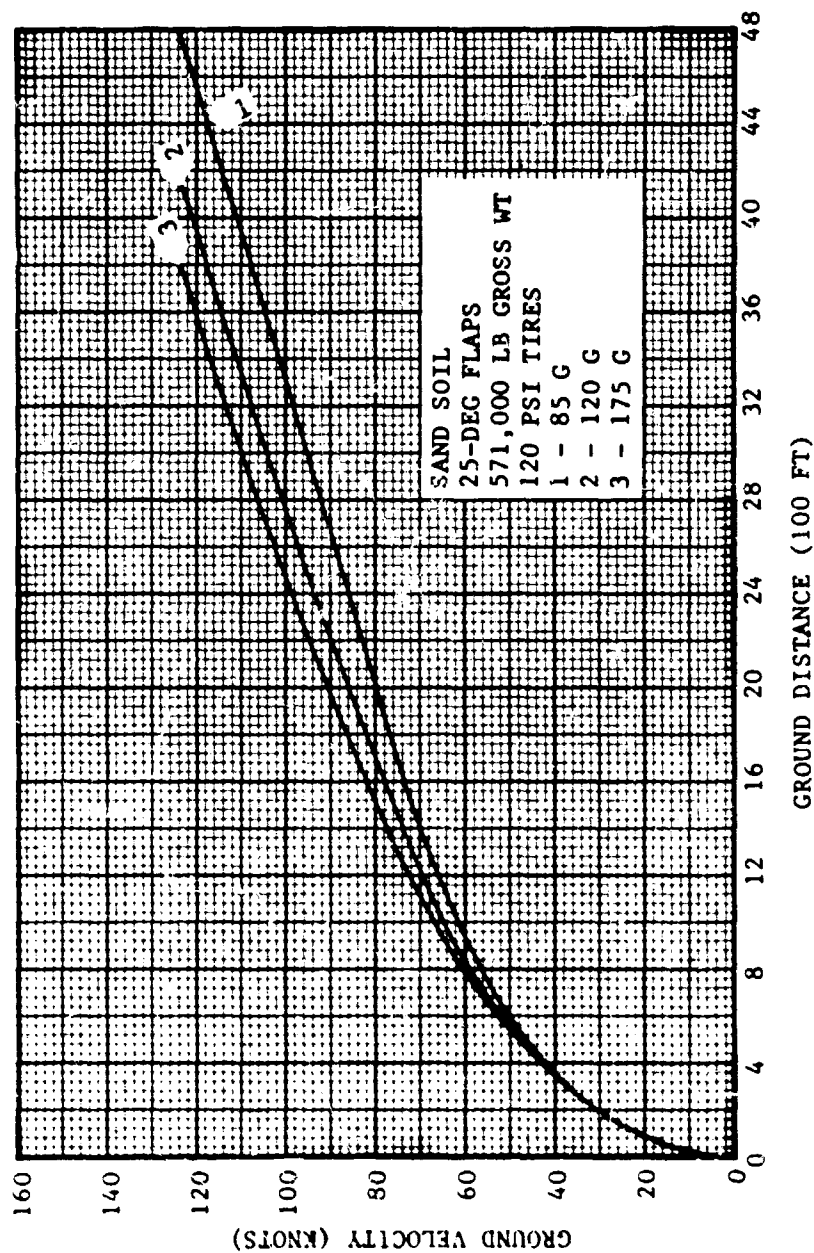


Figure 107. Airplane Velocity as a Function of Ground Distance for C-5 at 571,000 lb. Gross Weight

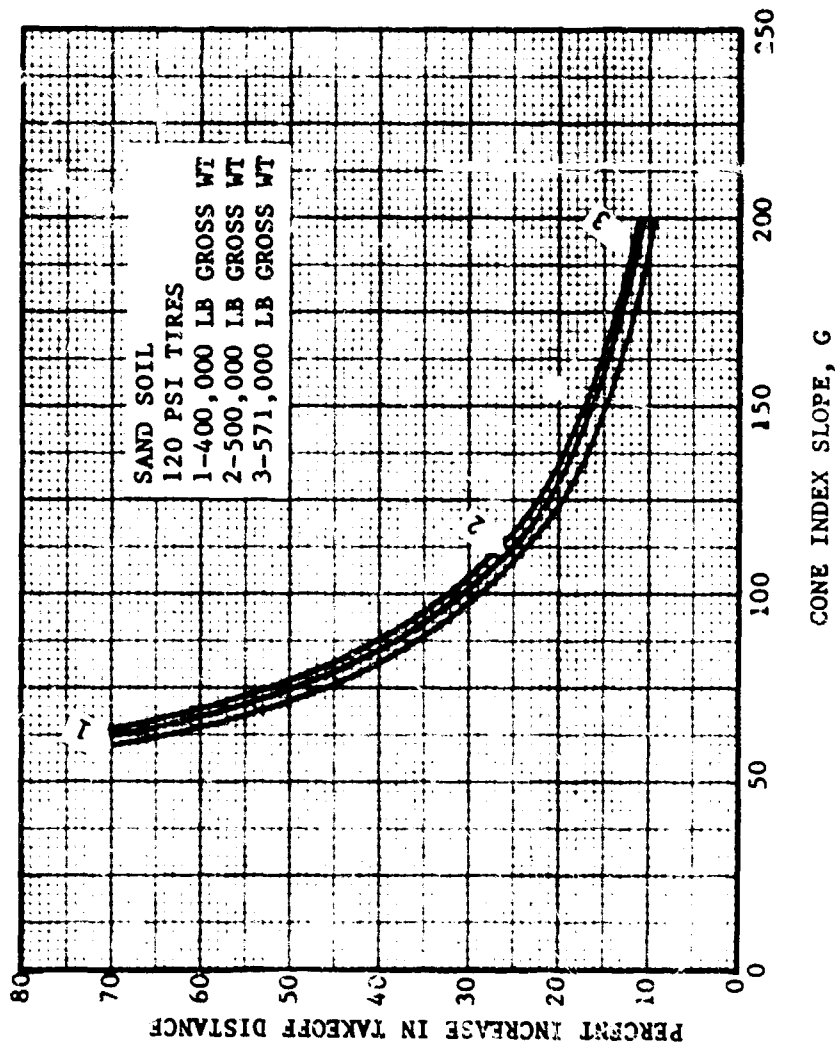


Figure 108 Percent Increase in Takeoff Distance Over Paved Surface for C-5 Aircraft

## SECTION VII

### AREAS FOR FURTHER DEVELOPMENT

Discussion - In a technology such as the one described in the preceding sections, there always exists a number of areas where because of limited time or lack of better scientific evidence, assumptions and simplifications are made in the techniques used. In the case of predicting soil drag and soil sinkage under dynamic deformation, a method was developed based on empirical curves which forced analytical results to conform to a limited amount of test data. In this section we will attempt to point out a few areas where improvement and extended verification of techniques and assumptions should be made.

Areas Where Further Development is Required - A number of areas have been observed where further study could provide a more complete understanding of the mechanics of dynamic soil deformation caused by a rolling tire. These areas with some suggested avenues of improvement are discussed below.

2.1 Mobility Number - The present method uses the concept of Mobility Number developed by WES to predict soil sinkage and drag. The results of plotting mobility number for various tire, load and soil strength combinations has shown a great deal of scatter. The tires used were for both aircraft and land vehicles. An effort to minimize this mobility number scatter by considering only aircraft tires for example, could significantly improve the sinkage and drag predictions.

2.2 Dynamic Factor - The dynamic factor is a parameter which has been established to correct for high speed effects when scaling drag and sinkage values based on low speed tests to the range of interest for aircraft. The curve of Figure 6 was drawn based on a limited amount of test data most of which was in the low speed range. A simple study of some preliminary data obtained (Reference 6) has shown considerable deviation from Figure 6, particularly at high speeds. Additional studies of this dynamic deformation effect may prove fruitful in improving prediction accuracy.

2.3 Tire Lift Curve - The assumption has been made that the soil exerts a dynamic pressure and a corresponding lift on the tire much like an aircraft wing. Consequently, values of an associated tire lift coefficient were determined based on a point at which the tire reaches the planing velocity, and significant reduction in drag is observed. The value of lift coefficient controls the peak of the drag ratio velocity histories presented in previous sections and, as such, becomes quite important in the overall prediction technique. More studies of this "planing" phenomena and the variation of lift coefficient with tire configuration are required before a clear understanding of the effects can be attained.

2.4 Impingement Drag Coefficient - A parameter closely associated with the lift coefficient is impingement drag coefficient. This parameter shown in Figure 11 is controlled by lift coefficient through the planing velocity. The impingement drag coefficient has a significant influence on the shape of the drag ratio-velocity curves. The assumption of a constant level up to planing velocity and a low but constant value beyond 1.5 times the planing velocity may be too severe. Future studies will refine the curve shape to conform to actual test results.

2.5 Soil Strength Measurements - One parameter which affects the overall technique is the soil strength. A method is needed which will provide a simple repeatable measurement of soil strength for all types of soil. Present methods are either cumbersome or operator-dependent and, as such, provide a major hindrance to future soil dynamics studies.

## SECTION VIII

### CONCLUSIONS

1. Computer Programs - Three computer programs have been developed which will predict soil sinkage and resulting drag loads for an aircraft operating on clay and sandy type airfields. The three programs will allow assessment of loads and performance for varying quantities of vehicle descriptive data. The data requirements specified in this fashion will permit assessment of a wide variety of vehicles and configurations and permit a "quick look" or "detailed assessment" depending on the amount of time available to determine the necessary descriptive data.

The programs appear to give results which compare favorably with the limited experimental data, although further refinement and accuracy improvement will undoubtedly result when findings of a research program presently underway are incorporated.

Additional consideration should be given to the following areas which are the basic weaknesses in the generality of the programs.

a. Zero initial velocity cannot be used in the TAKOFF program because it results in a divergent solution caused by high zero velocity drag values which override thrust. Studies of initial loads to begin motion for a static soil sinkage case would provide an insight into this problem. Beginning calculation with two or three ft/sec initial velocity seems to solve this problem with TAKOFF.

b. The programs assume that regardless of the soil strength the minimum soil sinkage is 0.1 inch. This lower limit has been established to avoid negative sinkage coefficients as vertical loads becomes smaller near the end of a takeoff roll. As can be seen from Figures 34, 78 and other increased takeoff distance curves, the percent increase approaches 3 to 5 percent at high soil strengths. The fixed sinkage limit is partially responsible for the increased takeoff distance remaining at 3 to 5 percent even at very high soil strengths where normally one would expect it to approach zero. The limit could be lowered slightly but with questionable benefit since other factors such as a minimum rolling resistance coefficient of 0.03 also has an effect. This level was established on the basis that soil rolling resistance regardless of soil strength could not be less than the rigid surface rolling resistance. Additional testing may clarify this situation somewhat.

c. Another area where difficulty is encountered in using the TAKOFF program is in determining the range of soil strengths where realistic results can be obtained. If, for example, too low a value of soil strength is used the solution will diverge or reach some steady state

condition. Some consideration was given to the solution to this problem but no changes were made in the program to correct it. The method used in the present analysis was to begin the calculation with a very high soil strength such as 400 CI or 200 G and work to the lower strengths by checking the percent increase in takeoff distance over paved surface. Percent increase values approaching 100 were considered to give a practical lower limit on soil strength for the program. This has worked satisfactorily since no problem occurs until a lower limit of approximately 80 CI or 20 G is tried.

2. Method - The method, although in need of continued refinement, appears to give reasonably accurate results and, as such, provides the user with a technique for evaluating a number of technical problems associated with ground operation of aircraft which were heretofore only estimated with engineering judgment. Some areas where fruitful results can be obtained with the method are listed below.

- a. Determine takeoff performance on soil airfields for a particular configuration.
- b. Determine design load data for landing gear expected to be used on soil airfields.
- c. Optimize tire sizes for a particular aircraft design.
- d. Optimize tire geometry and number.
- e. Calculate dynamic effects of operation on soil airfields.

It is expected therefore that in the future, techniques such as the one given herein will be used as a standard design calculation for aircraft required to operate on improvised airfields.

## SECTION IX

### REFERENCES

1. Richmond, L. D.; Bruske, N. W.; DeBord, K. J., et al, "Aircraft Dynamic Loads From Substandard Landing Sites", Part II, AFFDL TR-67-145, W-PAFB, Ohio.
2. Richmond, L. D.; Bruske, N. W.; DeBord, K. J., et al, "Aircraft Dynamic Loads From Substandard Landing Sites", Part V, Vol I, AFFDL TR-67-145, W-PAFB, Ohio.
3. C-135 Flight Performance Handbook, T. O. IC-13, KA-1-1.
4. C-141A Performance Substantiating Data Report, ER-8330, 18 Jan 67, Lockheed Georgia Co.
5. C-141 Flight Performance Handbook, T. O. IC-141-1-1.
6. Sharp, A. L., "Preliminary Wheel-Soil Dynamic Factor Behavior from Single Wheel Dynamometer Data", Test Report FDDS-68-1, February 68

A P P E N D I X   A

LISTING OF COMPUTER PROGRAMS

COMPUTER PROGRAM

TAKOFF

```

$1BFTC TAKCFF  M94,XR7,DECK
C*****
C  THIS PROGRAM CALCULATES THE TAKECFF PERFORMANCE TIME HISTORY
C  FOR A CONVENTIONAL AIRCRAFT OPERATING ON CLAY AND SANDY SOIL.
C  CODE WRITTEN BY ALFRED L. SHARP,AFFDL(FDCS) WPAFB OHIO PH. 2555584
C  INPUT DATA REQUIRED-
C  W=GROSS WEIGHT OF VEHICLE
C  AW=WING AREA
C  CL=LIFT COEFFICIENT DURING TAKECFF
C  CD=DRAG COEFFICIENT DURING TAKECFF
C  SIG=DENSITY RATIO
C  K=NUMBER OF PAIRS OF THRUST-VELOCITY VALUES (ONE ENGINE)
C  XVEL=K VALUES OF VELOCITY
C  YTH=K VALUES OF THRUST
C  DMB=DISTANCE BETWEEN NOSE AND MAIN GEAR STRUT
C  DCG=DISTANCE FROM MAIN GEAR STRUT TO CG
C  WNG=NUMBER OF NCSE GEAR WHEELS
C  WMG=NUMBER OF MAIN GEAR WHEELS
C  BN=NOSE GEAR TIRE WIDTH
C  DN=NOSE GEAR TIRE DIAMETER
C  BM=MAIN GEAR TIRE WIDTH
C  DM=MAIN GEAR TIRE DIAMETER
C  HTN=NCSE TIRE SECTION HEIGHT
C  HTM=MAIN TIRE SECTION HEIGHT
C  RHCS=SOIL DENSITY
C  SLCPE=SLOPE OF RUNWAY
C  NTANDN=NUMBER OF NOSE GEAR TANDEM WHEEL SETS
C  NTANDM=NUMBER OF MAIN GEAR TANDEM WHEEL SETS
C  NTYP=SOIL TYPE (CLAY=1,SAND=2)
C  NENG=NUMBER OF ENGINES
C  N=NUMBER OF PAIRS OF TIRE LOAD-DEFLECTION VALUES
C  (CNE NOSE AND ONE MAIN)
C  XFVN=N VALUES OF NOSE TIRE VERTICAL LOAD
C  YDFN=N VALUES OF NCSE TIRE DEFLECTION
C  XFVM=N VALUES OF MAIN TIRE VERTICAL LOAD
C  YDFM=N VALUES OF MAIN TIRE DEFLECTION
C  CI=CCNE INDEX OF SOIL (CLAY)
C*****
TAKOF001
TAKOF002
TAKOF003
TAKOF004
TAKOF005
TAKOF006
TAKOF007
TAKOF008
TAKOF009
TAKOF010
TAKOF011
TAKOF012
TAKOF013
TAKOF014
TAKOF015
TAKOF016
TAKOF017
TAKOF018
TAKOF019
TAKOF020
TAKOF021
TAKOF022
TAKOF023
TAKOF024
TAKOF025
TAKOF026
TAKOF027
TAKOF028
TAKOF029
TAKOF030
TAKOF031
TAKOF032
TAKOF033
TAKOF034
TAKOF035
TAKOF036
TAKOF037

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C      G=CCNE INDEX OF SOIL (SAND)
C      SO=INITIAL DISTANCE (O.)
C      VO=INITIAL VELOCITY (NORMALLY 2 TO 3 FT/SEC)
C      AC=INITIAL ACCELERATION (O.)
C      DT=INTEGRATION INTERVAL
C      ZS=GUESS AT SINKAGE
C      VTO=VELOCITY REQUIRED BEFORE TAKEOFF
C*****
COMMON/CRAFT/W,AW,CL,CD,SIG,K,NENG
COMMON/GEAR/DWB,DCG,WNG,WMG,NTANDN,NTANDM,N,BN,DN,BM,DM,HTN,HTM
COMMON/SOIL/CI,B,D,FV,ZI,HT,G,V(2),ZS,CMEGAC,OMEGAS,RHQS,SLCPE
COMMON/TABLES/XCI(11),YCLT(11),XVOVP(4),YCDI(4),XFVN(20),YDFN(20),
1XFVM(20),YDFM(20),XVEL(20),YTH(20)
COMMON/TYPE/NTYP
COMMON/PP/Q(2)
COMMON/STAR1/MU1P,MU2P
COMMON/SINK1/Z1N,Z2N,Z1M,Z2M
COMMON/DRAG1/FDNCSE,FDMAN
COMMON/WML/FVCG,RRC
COMMON/TRAP/SINN(2)
COMMON/ Y(2)
COMMON/ A(2),BB(19)
DATA(A(1),I=1,2)/6H CLAY ,6HSANDY /
DATA BB/19*6H*****/
REAL MU1P,MU2P
READ(5,20)AW,CL,CD,SIG,K
FORMAT(4F12.4,I12)
READ(5,30) (XVEL(I),I=1,K)
READ(5,30) (YTH(I),I=1,K)
FORMAT(6F12.4)
READ(5,30)DWB,WNG,WMG,BN,DN,BM,DM,HTN,HTM,RHQS,SLOPE
READ(5,31)NTANDN,NTANDM,NTYP,NENG,N
FORMAT(5I12)
READ(5,30) (XFVN(I),I=1,N)
READ(5,30) (YDFN(I),I=1,N)
READ(5,30) (XFVM(I),I=1,N)
READ(5,30) (YDFM(I),I=1,N)
READ(5,30) SC,VC,AQ,DT,ZS
READ(5,30) CI,G,RRC,W,DCG,VTO

```

TAKOF038  
TAKOF039  
TAKOF040  
TAKOF041  
TAKOF042  
TAKOF043  
TAKOF044  
TAKOF045  
TAKOF046  
TAKOF047  
TAKOF048  
TAKOF049  
TAKOF050  
TAKOF051  
TAKOF052  
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TAKOF062  
TAKOF063  
TAKOF064  
TAKOF065  
TAKOF066  
TAKOF067  
TAKOF068  
TAKOF069  
TAKOF070  
TAKOF071  
TAKOF072  
TAKOF073  
TAKOF074  
TAKOF075  
TAKOF076

35	WRITE(6,37) 88	TAKOF077
37	FORMAT(1H1, //9X, 19A6/) )	TAKOF078
	IF(RRC.GT.O.) GO TO 39	TAKOF079
	IF(NTYP.EQ.1) GO TO 32	TAKOF080
	CII=G	TAKOF081
	GO TO 36	TAKOF082
32	CII=CI	TAKOF083
36	WRITE(6,38) A(NTYP),CII,VO	TAKOF084
38	FORMAT(1H 30X,51HTAKEOFF PERFORMANCE OF AN AIRCRAFT OPERATING FROMTAKOF085	
	1 A/31X,A6,27FFIELD WITH A CONE INDEX OF ,F4.0,24H AND INITIAL VELO	TAKOF086
	2CITY OFF4.1,8H FT/SEC./)	TAKOF087
	GO TO 42	TAKOF088
39	WRITE(6,41) RRC,VO	TAKOF089
41	FORMAT(1H 30X,51HTAKEOFF PERFORMANCE OF AN AIRCRAFT OPERATING FROMTAKOF090	
	1M A/31X,42HPAVED RUNWAY WITH FRICTION COEFFICIENT OF ,F5.3,25H ANDTAKOF091	
	2 INITIAL VELOCITY OF ,F4.1,8H FT/SEC./)	TAKOF092
42	WRITE(6,43) 88	TAKOF093
43	FORMAT(9X,19A6/////)	TAKOF094
	IF(RRC.GT.O.) GO TO 45	TAKOF095
	WRITE(6,44)W,AW,BN,DN,CL,CD,8M,DM,SIG,SLOPE,NTANDN,VTC,RHOSTAKOF096	
	1,DWB,DCG	TAKOF097
44	FORMAT(1H 5X,11HWEIGHT = ,E14.7,3X,11HWING AREA= E14.7,3X13HW NTAKOF098	
	10SE TIRE= ,E14.7,3X,13HD NCSE TIRE= ,E14.7//6X,11HCL (TO) = ,E14.TAKOF099	
	27,3X,11HCD (TO) = ,E14.7,3X,13HW MAIN TIRE= E14.7,3X,13HD MAIN TITAKOF100	
	3RE= ,E14.7//6X,11HALT (SIG)= ,E14.7,3X,11HSLOPE = ,E14.7,3X,13HTAKOF101	
	4N TANDEM = ,12,15X,13HM TANDEM = ,12//6X,11HVTO(REQD)= ,E14.7,TAKOF102	
	53X,11HRHO SOIL = ,E14.7,3X,13HWHEEL BASE = ,E14.7,3X,13HCG LOCATIOTAKOF103	
	6N= ,E14.7)	TAKOF104
	GO TO 47	TAKOF105
45	WRITE(6,46)W,AW,CL,CD,SIG,SLOPE	TAKOF106
46	FORMAT(1H 5X,11HWEIGHT = ,E14.7,3X,11HWING AREA= ,E14.7,3X,13HCTAKOF107	
	1L TAKEOFF = ,E14.7,3X,13HCD TAKEOFF = ,E14.7//6X,11HALT (SIG)= ,E1TAKOF108	
	24.7,3X,11HSLOPE = ,E14.7)	TAKOF109
47	T=0.	TAKOF110
	NN=2	TAKOF111
	Y(1)=SQ	TAKOF112
	Y(2)=VO	TAKOF113
	Q(1)=0.	TAKOF114
	Q(2)=0.	TAKOF115



	3G-LB	RATIO	SINKAGE	SINKAGE)	
	GC TC 92				TAKOF155
91	WRITE(6,51)				TAKOF156
	WRITE(6,52)				TAKOF157
52	FORMAT(1H ,4X,4H TIME,4X,12H ACCELERATION,2X,8H DISTANCE,9X,8H VELOCITY				TAKOF158
	1Y)				TAKOF159
92	WRITE(6,80)				TAKOF160
80	FORMAT(1H0 1CX,24H TAKEOFF VELOCITY REACHED)				TAKOF161
	GC TC 34				TAKOF162
95	WRITE(6,70) T,Q(2),Y(1),Y(2),V(2)				TAKOF163
70	FORMAT(1H 10E12.5)				TAKOF164
	GC TC 76				TAKOF165
	END				TAKOF166
					TAKOF167

```

$18FTC DRAGX   M94,XR7,DECK
SUBROUTINE DRAG(NTYP,FD,NTAND,Z1P)
C*****
C SUBROUTINE DRAG CALCULATES WHEEL-SOIL DRAG FOR EITHER A SINGLE
C   CR TANDEM WHEEL FOR EITHER CLAY OR SANDY SOIL.
C
C ROUTINE REQUIREMENTS-
C   CMEGAS AND/OR OMEGAS FROM ROUTINGESINK-THROUGH COMMON
C   FV FROM ROUTINE FVG
C   ROUTINE LOOK FOR TABLE LOOK-UP(TABLE VALUES THROUGH COMMON)
C
C CALLING SEQUENCE
C   CALL DRAG(N,D,NT,Z)
C   WHERE-
C       N=TYPE SOIL-1 FOR CLAY,2 FOR SAND
C       D=CALCULATED DRAG
C       NT=NUMBER TANDEM-WHEEL SETS
C       Z=FIRST PASS DYNAMIC SINKAGE
C*****
COMMON/SOIL/CI,B,D,FV,ZT,HT,G,V(2),ZS,CMEGAC,OMEGAS,RHOS,SLOPE
COMMON/TABLES/XCI(11),YCLT(11),XVOVP(4),YCDI(4),XVFN(20),VDFN(20),
1X FVM(20),YDFM(20),XVEL(20),YTH(20)
COMMON/STAR/MU1P,MU2P
REAL MU1P,MU2P
GO TO (10,20),NTYP
10 MU1P=0.4072/(OMEGAC-0.8713)-0.0206
   IF(MU1P.LE.0.03) MU1P=0.03
   IF(NTAND.EQ.0) GC TC 25
   MU2P=MU1P
   GC TC 25
20 MU1P=0.6+90/(OMEGAS-2.2222)+0.0366
   IF(MU1P.LE.0.03) MU1P=0.03
   IF(NTAND.EQ.0) GC TC 25
   MU2P=0.7085/(OMEGAS-2.1739)+0.0195
   CI=0.5*(1.68781/12.)*2*RHOS*B
   AT=2.3*ZT*SQRT(B*D)
   GC TO (26,27),NTYP
26 CALL LCUK (CI,CLT,XCI,YCLT,11)

```

DRAG0380  
 DRAG0390  
 DRAG0400  
 DRAG0410  
 DRAG0420  
 DRAG0430  
 DRAG0440  
 DRAG0450  
 DRAG0460  
 DRAG0470  
 DRAG0480  
 DRAG0490  
 DRAG0500  
 DRAG0510  
 DRAG0520  
 DRAG0530  
 DRAG0540

```

27 GC TC 28
    CI=G*8/2.
    CALL LCOK (CI,CLT,XCI,YCLT,11)
28 VP=SCRT(288.*FV/(AT*RHCS*CLT))
    VOVP=V(2)*1.685/VP
    CALL LOOK (VCVP,CDI,XVOVP,YCDI,4)
    IF(NTAND.EQ.0) GC TO 40
    IF(NTYP.GT.1) GC TO 30
    TWF=0.4
    GC TC 35
    TWF=1.C
30 FS=CI*CDI*Z1P*V(2)*V(2)
35 FD=(MULP+MU2P)*FV+FS*(1.+TWF)
    GC TC 45
40 FD=MULP*FV+CI*CDI*Z1P*V(2)*V(2)
45 RETURN
    END
  
```

```

SINFTC SINX  M94,XR7,DECK
SUBROUTINE SINK (NTYP,Z1P,Z2P,NTAND,INDW)
C*****
C ROUTINE CALCULATES SOIL SINKAGE FOR FIRST AND SECOND PASSES
C OF A TIRE ROLLING ON CLAY CR SANDY SOIL
C
C CALLING SEQUENCE-
C CALL SINK (NTYP,Z1P,Z2P,NTAND)
C WHERE-
C NTYP=SOIL TYPE (CLAY=1,SAND=2)
C Z1P=FIRST PASS SINKAGE
C Z2P=SECOND PASS SINKAGE
C NTAND=NUMBER OF TANDEM WHEEL SETS
C THE FOLLOWING IS REQUIRED THROUGH COMMON
C COMMON/SOIL/CI,B,D,FV,ZT,HT,V(2),ZS,OMEGAC,CMEGAS,RHOS,
C SLCPE
C*****
COMMON/SOIL/CI,B,D,FV,ZT,HT,G,V(2),ZS,CMEGAC,CMEGAS,RHOS,SLOPE
COMMON/TRAP/SINN(2)
REAL LT
Z2P=0.0
IF(SINN(INDW).GT.0.) GO TO 60
INT=1
ZA=ZS+ZT
LT=2.*SQRT(D*ZA-ZA**2)
IF(V(2).EQ.0.) GC TO 2
TP=LT/(V(2)*1.689*12.)
GO TO 5
DF=1.
GC TC 6
DF=1.0+1.34*EXP(-1.27*TP)
GC TC (10,20),NTYP
OMEGA=CI*B*D*SQRT(ZT/HT)/FV
OMEGAC=OMEGA*DF/1.6
Z1P= (0.1208/(OMEGAC-0.9468)-0.0095)*D
IF(Z1P.LE.0.1) GO TO 32
GC TO 25
CMEGAS=(Z1P**D)*1.5*(ZT/HT)/FV

```

SINK0000  
SINK0010  
SINK0020  
SINK0030  
SINK0040  
SINK0050  
SINK0060  
SINK0070  
SINK0080  
SINK0090  
SINK0100  
SINK0110  
SINK0120  
SINK0130  
SINK0140  
SINK0150  
SINK0160  
SINK0170  
SINK0180  
SINK0190  
SINK0200  
SINK0210  
SINK0220  
SINK0230  
SINK0240  
SINK0250  
SINK0260  
SINK0270  
SINK0280  
SINK0290  
SINK0300  
SINK0310  
SINK0320  
SINK0330  
SINK0340  
SINK0350  
SINK0360  
SINK0370  
SINK0380

```

OMEGAS=OMEG8*DF/1.6
Z1P=(0.3439/(OMEGAS-0.6239)-0.0018)*D
IF(Z1P.LE.0.1) GO TO 32
25 EPS=ABS(Z1P-ZS)
IF(EPS-.01.LT.0.) RETURN
INT=INT+1
IF(INT.GT.100) GC TO 27
26 ZS=Z1P
GO TO 1
27 WRITE(6,28)
28 FORMAT(1H0 35HSINKAGE ITERATIONS GREATER THAN 100)
STOP
32 SINN(INDW)=0.1
33 ZA=0.1+ZT
LT=2.*SQRT(D*ZA-ZA**2)
TP=LT/(V(2)*20.268)
DF=1.0+1.34*EXP(-1.27*TP)
GC TO (70,80),NTYP
70 OMEGA=C1*8*D*SQRT(ZT/HT)/FV
OMEGAC=OMEGA*DF/1.6
GO TO 50
80 OMEG8= G*(8*D)**1.5*(ZT/HT)/FV
OMEGAS=CMEG8*DF/1.6
50 RETURN
60 Z1P=SINN(INDW)
GO TO 33
END
SINK0390
SINK0400
SINK0410
SINK0420
SINK0430
SINK0440
SINK0450
SINK0460
SINK0470
SINK0480
SINK0490
SINK0500
SINK0510
SINK0520
SINK0530
SINK0540
SINK0550
SINK0560
SINK0570
SINK0580
SINK0590
SINK0600
SINK0610
SINK0620
SINK0630
SINK0640
SINK0650

```

```

$IBFTC DEFLX  M94,XR7,DECK
SUBROUTINE DEFL(X,Y,N,K)
C*****
C SUBROUTINE DEFL CALCULATES TIRE DEFLECTION USING ROUTINE LOOK
C AND AN ARRAY OF TIRE-DEFLECTION VS VERTICAL LOAD VALUES
C
C CALLING SEQUENCE-
C CALL DEFL(X,Y,N,K)
C WHERE-
C X=VERTICAL TIRE LOAD
C Y=RESULTANT DEFLECTION
C N=SIZE OF ARRAYS
C K=1 FOR NOSE-WHEEL TIRE,2 FOR MAIN-GEAR TIRE
C
C*****
COMMON/TABLES/XCI(11),YCLT(11),XVOVP(4),YCDI(4),XFVN(20),YDFN(20),
1XFVM(20),YDFM(20),XVEL(20),YTH(20)
GO TO (10,20),K
10 CALL LOOK (X,Y,XFVN,YDFN,N)
RETURN
20 CALL LOOK (X,Y,XFVM,YDFM,N)
RETURN
END
DEFL0000
DEFL0010
DEFL0020
DEFL0030
DEFL0040
DEFL0050
DEFL0060
DEFL0070
DEFL0080
DEFL0090
DEFL0100
DEFL0110
DEFL0120
DEFL0130
DEFL0140
DEFL0150
DEFL0160
DEFL0170
DEFL0180
DEFL0190
DEFL0200
DEFL0210
DEFL0220

```

```

$IBFTC LOXXX  M94,XR7,DECK
SUBROUTINE LOOK(X,Y,XX,YY,N)
C*****
C SUBROUTINE LOOK GIVES ONE DIMENSIONAL TABLE LOOK-UP USING LINEAR
C INTERPOLATION
C CALLING SEQUENCE-
C CALL LOOK(X,Y,XX,YY,N)
C WHERE-
C X=INDEPENDENT VARIABLE
C Y=INTERPOLATED RESULT
C XX=ARRAY OF INDEPENDENT VARIABLES
C YY=RESULT ARRAY
C N=DIMENSION OF XX AND YY
C*****
DIMENSION XX(N),YY(N)
IF(X.LT.XX(1).OR.X.GT.XX(N)) GO TO 30
DO 10 I=1,N
IF(X-XX(I))20,15,10
CONTINUE
Y=YY(I)
RETURN
Y=YY(I-1)+((YY(I)-YY(I-1))*(X-XX(I-1))/(XX(I)-XX(I-1)))
RETURN
WRITE(6,35) X
35 FORMAT(1H0,25HVALUE OUTSIDE TABLE X = ,E15.8)
STOP
END

```



```

$18FTC TOTDGX M94,XR7,DECK
SUBROUTINE TOTDG (NTYP,TDRAG)
C*****
C ROUTINE CALCULATES TOTAL SOIL DRAG FOR NCSE WHEEL AND MAIN WHEELS
C NTYP=TYPE SOIL
C TDRAG=TOTAL DRAG IN POUNDS
C*****
COMMON/SCIL/CI,B-D,FV,ZT,HT,G,V12),ZS,OMEGAC,OMEGAS,RHOS,SLOPE
COMMON/GEAR/DWB,DCG,WNG,WRC,NTANDN,N,BN,DM,HTN,HTM
COMMON/DRAG1/FDNCSE,FDM,AIN
COMMON/SINK1/ZIN,Z2N,Z1M,Z2M
COMMON/STAR/MULP,MU2P
COMMON/STAR1/MUN,MUM
COMMON/WML/FVCG,RRC
REAL MULP,MU2P,MUN,MUM
CALL FVG(FVNGS,FVMGS,V(21))
IF(RRC.GT.0.) GO TO 60
FV=FVNGS
B=BN
D=DN
HT=HTN
CALL DEFL(FV,ZT,N,1)
CALL SINK(NTYP,ZIN,Z2N,NTANDN,1)
CALL DRAG(NTYP,FCN,NTANDN,ZIN)
MUN=MULP
IF(NTANDN.EQ.0) GO TO 10
TANDN=NTANDN
FDNCSE=FDN*TANDN
GO TO 15
10 FNCSE=FDN*WNG
15 FV=FVMGS
B=BM
D=DM
HT=HTM
CALL DEFL(FV,ZT,N,2)
CALL SINK(NTYP,Z1M,Z2M,NTANDM,2)
CALL DRAG(NTYP,FDM,NTANDM,Z1M)
MUM=MULP
IF(NTANDM.EQ.0) GO TO 20
TOTDG000
TOTDG010
TOTDG020
TOTDG030
TOTDG040
TOTDG050
TOTDG060
TOTDG070
TOTDG080
TOTDG090
TOTDG100
TOTDG110
TOTDG120
TOTDG130
TOTDG140
TOTDG150
TOTDG160
TOTDG170
TOTDG180
TOTDG190
TOTDG200
TOTDG210
TOTDG220
TOTDG230
TOTDG240
TOTDG250
TOTDG260
TOTDG270
TOTDG280
TOTDG290
TOTDG300
TOTDG310
TOTDG320
TOTDG330
TOTDG340
TOTDG350
TOTDG360
TOTDG370
TOTDG380

```

TOTDG390  
TOTDG400  
TOTDG410  
TOTDG420  
TOTDG430  
TOTDG440  
TOTDG450  
TOTDG460  
TOTDG470

TANDM=NTANDM  
FDMAIN=FDN\*TANDM\*2.  
GO TO 30  
20 FDMAIN=FDN\*WMG\*2.  
30 TDRAG=FDNOSE+FDMAIN  
RETURN  
60 TDRAG=FVCG\*RRC  
RETURN  
END

```

$IBFTC DER      M94,XR7,DECK
  SUBROUTINE F(X,V,P)
C*****
C  SUBROUTINE DER DETERMINES THE INSTANTANEOUS ACCELERATION
C  DUE TO FORCES ACTING ON AIRCRAFT. ROUTINE IS CALLED
C  BY RKDES
C*****
  COMMON/CRAFT/W,AW,CL,CD,SIG,K,NENG
  COMMON/SCIL/CI,B,D,FV,ZT,HT,G,E(2),ZS,OMEGAC,OMEGAS,RHOS,SLOPE
  COMMON/TYPE/NTYP
  COMMON/PP/C(2)
  DIMENSION P(2),V(2)
  P(1)=V(2)
  Q(1)=P(1)
  E(2)=V(2)/1.689
  CALL THRUST(E(2),TH,K)
  CALL ICTDG (NTYP,TDAG)
  CALL PAROG (E(2),AD)
  P(2)=32.174/W*(TH-AD-TDRAG-W*SLOPE)
  Q(2)=P(2)
  RETURN
  END
DER00000
DER00010
DER00020
DER00030
DER00040
DER00050
DER00060
DER00070
DER00080
DER00090
DER00100
DER00110
DER00120
DER00130
DER00140
DER00150
DER00160
DER00170
DER00180
DER00190
DER00200
DER00210

```

```

$IBFTC FVXXX  M94,XR7,DECK
SUBROUTINE FVG (FVNGS,FVMGS,V)
C*****
C ROUTINE CALCULATES WEIGHT DISTRIBUTION FOR CG VARIATION AND
C THE RESULTANT LOAD ON NOSE AND MAIN GEAR STRUTS
C (LIFT MINUS WEIGHT)
C FVNGS=VERTICAL LOAD ON NOSE GEAR STRUT
C FVMGS=VERTICAL LOAD ON MAIN GEAR STRUT
C V=VELOCITY
C*****
COMMON/CRAFT/W,AW,CL,CD,SIG,K,NEGS
COMMON/GEAR/DWB,DCG,WNG,WMG,NTANDN,N,BN,DN,8M,DM,HTN,HTM
COMMON/WML/FVCG,RRC
REAL L
L=CL*SIG*V*V*AW/295.371
FVCG=W-L
IF(RRC.GT.0.) RETURN
FVNGS=FVCG*DCG/(DWB*WNG)
FVMGS=FVCG*(DWB-DCG)/(DWB*2.*WMG)
RETURN
END
FVG00000
FVG00010
FVG00020
FVG00030
FVG00040
FVG00050
FVG00060
FVG00070
FVG00080
FVG00090
FVG00100
FVG00110
FVG00120
FVG00130
FVG00140
FVG00150
FVG00160
FVG00170
FVG00180
FVG00190
FVG00200

```

```

$IBFTC PARCGX M94,XR7,DECK
SUBROUTINE PARCG(V,D)
C*****
C ROUTINE CALCULATES THE AERODYNAMIC DRAG ACTING ON VEHICLE
C*****
COMMGN/CRAFT/W,AW,CL,CD,SIG,K,NENGs
D=CD*SIG*V*V*AW/295.371
RETURN
END
PARCG000
PARCG010
PARCG020
PARCG030
PARCG040
PARCG050
PARCG060
PARCG070
PARCG080

```

```

$IBFTC THRUSX M94,XR7,DECK
SUBROUTINE THRUST(V,TH,K)
C*****
C SUBROUTINE THRUST FINDS VALUE OF THRUST FOR A PARTICULAR SPEED
C AND DETERMINES TOTAL ENGINE THRUST
C*****
COMMON/CRAFT/W,Ah,CL,CO,SIG,K,NENGs
COMMON/TABLES/XCI(11),YCLT(11),XVOVP(4),YCDI(4),XFVN(20),YDFN(20),
1XFVN(20),YDFN(20),XVEL(20),YTH(20)
CALL LOOK(V,TH,XVEL,YTH,K)
E=NENGs
TH=TH+E
RETURN
END
THRUS000
THRUS010
THRUS020
THRUS030
THRUS040
THRUS050
THRUS060
THRUS070
THRUS080
THRUS090
THRUS100
THRUS110
THRUS120
THRUS130

```

```

918FTC RUMKUT M94,XR7,DECK
      SUBROUTINE RKDES(X,Y,N,DX)
C*****
C      SUBROUTINE RKDES IS A RUNGE-KUTTA DIFFERENTIAL EQUATION
C      SOLVER WRITTEN BY H. PETERSEN AND F. SANSCH (SESC) WPAFB OHIO
C      PH. 2553590.
C      CALLING SEQUENCE-
C      CALL RKDES (X,Y,N,DX)
C      WHERE-X=INDEPENDENT VARIABLE
C      Y=VECTOR OF N DEPENDENT VARIABLES
C      N=ORDER OF SYSTEM TO BE SOLVED
C      DX=COMMUNICATION INTERVAL
C      RKDES REQUIRES A SUBROUTINE F TC EVALUATE DERIVATIVES.
C*****
      DIMENSION Y(99),Y0(99),YT(99),YP(99),PO(99),PI(99),P2(99),P3(99)
      IF(N.LT.100) GO TO 1
      WRITE(6,100) N
100  FORMAT(1PA,10X,11HTHE ORDER (,I3,27H) OF THE SYSTEM EXCEEDS 99.,/,RKDES170
      C      11X,47HCHANGE DIMENSION STATEMENT IN SUBROUTINE RKDES.,RKDES180
      C      /,11X,18HEXECUTION DELETED.)
      STOP
1    X0=X
      X=X+DX
      H=DX
2    IF(ABS(H).GT.ABS(X-XC)) H=X-X0
      DO 4 I=1,N
4    Y0(I)=Y(I)
      HT=H
      XT=X0
      RMAXP = 1.E37
      DO 5 I=1,N
5    YT(I)=Y0(I)
      ASSIGN 6 TC K
      GO TO 20
6    DO 7 I=1,N
7    YP(I)=Y(I)
      HT=C.5*H
      ASSIGN 9 TC K
      GO TO 20
      RKDES000
      RKDES010
      RKDES020
      RKDES030
      RKDES040
      RKDES050
      RKDES060
      RKDES070
      RKDES080
      RKDES090
      RKDES100
      RKDES110
      RKDES120
      RKDES130
      RKDES140
      RKDES150
      RKDES160
      RKDES170
      RKDES180
      RKDES190
      RKDES200
      RKDES210
      RKDES220
      RKDES230
      RKDES240
      RKDES250
      RKDES260
      RKDES270
      RKDES280
      RKDES290
      RKDES300
      RKDES310
      RKDES320
      RKDES330
      RKDES340
      RKDES350
      RKDES360
      RKDES370
      RKDES380

```

```

9      DO 10 I=1,N
10     Y(I)=Y(I)
      XT=XO+HT
20     ASSIGN 11 TO K
      CALL F(XT,YT,PO)
21     DO 21 I=1,N
      Y(I)=Y(I)+O.5*HT*PO(I)
      CALL F(XT+O.5*HT,Y,P1)
      DO 22 I=1,N
      Y(I)=Y(I)+.5*HT*P1(I)
      CALL F(XT+O.5*HT,Y,P2)
22     DO 23 I=1,N
      Y(I)=Y(I)+HT*P2(I)
      CALL F(XT+HT,Y,P3)
      DO 24 I=1,N
24     Y(I)=Y(I)+HT*(PC(I)+2.*(P1(I)+P2(I)+P3(I)))/6.
      GO TO K,(6,9,11)
11     RMAX=C.
      DO 12 I=1,N
12     RMAX=AMAX1(RMAX,.07*ABS((Y(I)-YP(I))/Y(I)))
      IF ((RMAX.GT.1.E-06).AND.(RMAX.LT.RMAXP)) GO TO 17
      XO=XO+H
      IF(XC.EQ.X) RETURN
      IF((RMAX.LT.1.E-7).OR.(RMAX.GT.RMAXP)) H=H+H
      GO TO 2
17     H=HT
      XT=XC
      DO 19 I=1,N
18     YP(I)=YT(I)
19     YT(I)=YO(I)
      RMAXP = RMAX
      GO TO 8
      END

```

```

RKDES390
RKDES400
RKDES410
RKDES420
RKDES430
RKDES440
RKDES450
RKDES460
RKDES470
RKDES480
RKDES490
RKDES500
RKDES510
RKDES520
RKDES530
RKDES540
RKDES550
RKDES560
RKDES570
RKDES580
RKDES590
RKDES600

RKDES610
RKDES620
RKDES630
RKDES640
RKDES650
RKDES660
RKDES670
RKDES680
RKDES690
RKDES700
RKDES710

```

COMPUTER PROGRAM

SOLDG2

\$IBFIC	SOLDG2	M94,XR7,DECK	SLDG2001
C			SLDG2002
C		ROUTINE CALCULATES SOIL DRAG FOR A COMPLETE SET OF TIRES FOR	SLDG2003
C		CONSTANT TAXI VELOCITY ON CLAY AND SAND SOILS.	SLDG2004
C		ROUTINE WRITTEN BY ALFRED L. SHARP, AFFDL(FDOS),WPAFB OHIO,	SLDG2005
C		PHONE 255-5584.	SLDG2006
C		DATA REQUIRED-	SLDG2007
C		W=WEIGHT OF VEHICLE	SLDG2008
C		ZS=GUESS AT DYNAMIC SINKAGE (0.5)	SLDG2009
C		V=VELOCITY OF TAXI	SLDG2010
C		BN=NOSE TIRE WIDTH	SLDG2011
C		DN=NOSE TIRE DIAMETER	SLDG2012
C		HTN=NOSE TIRE SECTION HEIGHT	SLDG2013
C		N=NUMBER OF PAIRS OF TIRE DEFLECTION VALUES TO BE READ	SLDG2014
C		AW=WING AREA	SLDG2015
C		BM=MAIN TIRE WIDTH	SLDG2016
C		DM=MAIN TIRE DIAMETER	SLDG2017
C		HTM=MAIN TIRE SECTION HEIGHT	SLDG2018
C		CL=LIFT COEFFICIENT DURING TAKEOFF	SLDG2019
C		CD=DRAG COEFFICIENT DURING TAKEOFF	SLD32020
C		DWB=DISTANCE BETWEEN NOSE AND MAIN GEAR STRUTS	SLDG2021
C		DCG=CENTER OF GRAVITY LOCATION (FT FORWARD OF MAIN STRUT)	SLDG2022
C		WMG=NUMBER OF MAIN GEAR TIRES PER STRUT	SLDG2023
C		RHOS=SOIL DENSITY	SLDG2024
C		SIG=ATMOSPHERIC DENSITY RATIO	SLDG2025
C		NTYP=TYPE OF SOIL DESIRED (CLAY=1,SAND=2)	SLDG2026
C		NTANDN=NUMBER OF NOSE TIRE TANDEM SETS	SLDG2027
C		NTANDM=NUMBER OF MAIN TIRE TANDEM SETS	SLDG2028
C		XFVN=N VALUES OF NOSE TIRE VERTICAL FORCE	SLDG2029
C		YDFN=N VALUES OF NOSE TIRE DEFLECTION	SLDG2030
C		XFVM=N VALUES OF MAIN TIRE VERTICAL FORCE	SLDG2031
C		YDFM=N VALUES OF MAIN TIRE DEFLECTION	SLDG2032
C		CI=CONE INDEX OF SOIL(ETHER CLAY OR SAND)	SLDG2033
C		CII=INITIAL SOIL STRENGTH	SLDG2034
C		DCI=INCREMENTAL SOIL STRENGTH	SLDG2035
C		CIMAX=MAXIMUM SOIL STRENGTH OF INTEREST	SLDG2036
C		VI=INITIAL TAXI VELOCITY	SLDG2037
C		DELV=INCREMENTAL TAXI VELOCITY	SLDG2038
C		VMAX=MAXIMUM TAXI VELOCITY OF INTEREST	SLDG2039
C			SLDG2040

COMMON/SOIL/CI,8,D,FV,ZI,HT,G,V,ZS,OMEGAC,OMEGAS,RHUS	SLDG2041
COMMON/TABLES/XCI(11),YCLT(11),XVOVP(4),YCDI(4),XFVN(20),YDFN(20),	SLDG2042
1XFVM(20),YDFM(20),XVEL(20),YTH(20)	SLDG2043
COMMON/STAR1/MULP,MU2P	SLDG2044
COMMON/SINK1/Z1N,Z2N,Z1M,Z2M	SLDG2045
COMMON/CRAFT/W,AW,CL,CD,SIG	SLDG2046
COMMON/GEAR/DWB,DCG,WNG,WMG,NTANDN,NTANDM,N,BN,DN,BM,DM,HTN,HTM	SLDG2047
COMMON/DRAG1/FDNOSE,FDMAIN	SLDG2048
COMMON/WML/FVCG	SLDG2049
DIMENSION A(2),BB(19)	SLDG2050
DATA(A(1),I=1,2)/6HCLAY ,6HSANDY /	SLDG2051
DATA BB/19*6H***** /	SLDG2052
REAL MULP,MU2P	SLDG2053
5 READ(5,10) W,ZS,BN,DN,HTN,N	SLDG2054
READ(5,20) AW,BM,DM,HTM,CL,CD	SLDG2055
READ(5,20) DWB,DCG,WNG,WMG,RHOS,SIG	SLDG2056
READ(5,15) NTYP,NTANDN,NTANDM	SLDG2057
15 FORMAT(3I12)	SLDG2058
10 FORMAT(5F12.4,I12)	SLDG2059
READ(5,20) (XFVN(I),I=1,N)	SLDG2060
READ(5,20) (YDFN(I),I=1,N)	SLDG2061
READ(5,20) (XFVM(I),I=1,N)	SLDG2062
READ(5,20) (YDFM(I),I=1,N)	SLDG2063
20 FORMAT(6F12.4)	SLDG2064
READ(5,20) CII,DCI,CIMAX,VI,DELV,VMAX	SLDG2065
25 FORMAT(4F12.4,2I12)	SLDG2066
CI=CII	SLDG2067
V=VI	SLDG2068
26 CALL TOTDG (NTYP,TDRAG)	SLDG2069
DR=TDRAG/FVCG	SLDG2070
FD=FDNOSE+FDMAIN	SLDG2071
WRITE(6,40) BB	SLDG2072
40 FORMAT(1H1,/,79X,19A6/)	SLDG2073
WRITE(6,41) A(NTYP),CI	SLDG2074
41 FORMAT(1H 30X,47H SOIL DRAG FOR COMPLETE SET OF TIRES ROLLING ON ,ASLDG2075	ASLDG2075
16,4H SOIL/31X,21H WITH A CONE INDEX OF ,F4.0,27H AND CONSTANT TAXI VSLDG2076	VSLDG2076
2ELOCITY//)	SLDG2077
WRITE(6,42) BB	SLDG2078
42 FORMAT(9X,19A6////)	SLDG2079

```

WRITE(6,30) W,V,BN,DN,NTANDN,NTANDM,BM,DM,FD,DR,ZIN,ZIM,FDMNOSE,FDMSLDG2080
1AIN,MUIP,MU2P
30  FORMAT(1H,5X,12HWEIGHT = ,E14.7,3X,12HVELOCITY = ,E14.7,3X,13SLDG2081
    1HW NOSE TIRE= ,E14.7,3X,13HD NOSE TIRE= ,E14.7//6X,12HN TANDEM = SLDG2082
    2,12,15X,12HM TANDEM = ,12,15X,13HW MAIN TIRE= ,E14.7,3X,13HD MAINSLDG2083
    3 TIRE= ,E14.7//6X,12HTOT DRAG = ,E14.7,3X,12HFD/FV = ,E14.7,3SLDG2084
    4X,13HN SINKAGE = ,E14.7,3X,13HM SINKAGE = ,E14.7//6X,12HNOSE DRASLDG2085
    5G = ,E14.7,3X,12HMAIN DRAG = ,E14.7,3X,13HMU STAR N = ,E14.7,3X,1SLDG2086
    63HMU STAR M = ,E14.7)
    V=V+DELV
    IF(V.GT.VMAX) GO TO 45
    GO TO 26
    45  CI=CI+DCI
    IF(CI.GT.CIMAX) GO TO 5
    V=VI
    GO TO 26
    END
SLDG2087
SLDG2088
SLDG2089
SLDG2090
SLDG2091
SLDG2092
SLDG2093
SLDG2094
SLDG2095
SLDG2096

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SLDG2097
SLDG2098
SLDG2099
SLDG2100
SLDG2101
SLDG2102
SLDG2103
SLDG2104
SLDG2105
SLDG2106
SLDG2107
SLDG2108
SLDG2109
SLDG2110
SLDG2111
SLDG2112
SLDG2113
SLDG2114
SLDG2115
SLDG2116
SLDG2117
SLDG2118
SLDG2119
SLDG2120
SLDG2121
SLDG2122
SLDG2123
SLDG2124
SLDG2125
SLDG2126
SLDG2127
SLDG2128
SLDG2129
SLDG2130
SLDG2131
SLDG2132
SLDG2133
SLDG2134
SLDG2135
SLDG2136

$IBFTC SINKX M94,XK7,DECK
SUBROUTINE SINK (NTYP,Z1P,Z2P,NTAND)
C*****
C ROUTINE CALCULATES SOIL SINKAGE FOR FIRST AND SECOND PASSES
C OF A TIRE ROLLING ON CLAY OR SANDY SOIL
C
C CALLING SEQUENCE-
C CALL SINK (NTYP,Z1P,Z2P,NTAND)
C WHERE-
C NTYP=SOIL TYPE (CLAY=1,SAND=2)
C Z1P=FIRST PASS SINKAGE
C Z2P=SECOND PASS SINKAGE
C NTAND=NUMBER OF TANDEM WHEEL SETS
C THE FOLLOWING IS REQUIRED THROUGH COMMON
C COMMON/SOIL/CI,B,D,FV,ZT,HT,V(2),ZS,OMEGAC,OMEGAS,RHDS,
C SLOPE
C*****
COMMON/SOIL/CI,B,D,FV,ZT,HT,G,V,ZS,OMEGAC,OMEGAS,RHDS
REAL LT
INT=1
1 ZA=ZS+ZT
LT=2.*SQRT(D*ZA-ZA**2)
IF(V.EQ.0.) GO TO 2
TP=LT/(V*1.689*12.)
GO TO 5
2 DF=1.
GO TO 6
3 DF=1.0+1.34*EXP(-1.27*TP)
6 GO TO (10,20),NTYP
10 OMEGA=CI*B*D*SQRT(ZT/HT)/FV
OMEGAC=OMEGA*DF/1.6
Z1P= (0.1208/(OMEGAC-0.9468)-0.0095)*D
IF(Z1P.LE.0.1) GO TO 32
IF(NTAND.EQ.0)GO TO 25
GO TO 25
20 OMEG8=CI*(B*D)**1.5*(ZT/HT)/FV
OMEGAS=OMEG8*DF/1.6
Z1P=(0.3439/(OMEGAS-0.6239)-0.0018)*D
IF(Z1P.LE.0.1) GO TO 32

```

SLDG2137  
SLDG2138  
SLDG2139  
SLDG2140  
SLDG2141  
SLDG2142  
SLDG2143  
SLDG2144  
SLDG2145  
SLDG2146  
SLDG2147  
SLDG2148  
SLDG2149  
SLDG2150  
SLDG2151  
SLDG2152  
SLDG2153  
SLDG2154  
SLDG2155  
SLDG2156  
SLDG2157  
SLDG2158  
SLDG2159

```

25 IF(NTAND.EQ.0)GO TO 25
   EPS=ABS(ZIP-ZS)
   IF(EPS-.01.LT.0.) RETURN
   INT=INT+1
   IF(INT.GT.100) GO TO 27
26 ZS=ZIP
   GO TO 1
27 WRITE(6,28)
28 FORMAT(1H0 3HSINKAGE ITERATIONS GREATER THAN 100)
   STOP
32 ZIP=0.1
   ZA=0.1+ZT
   LT=2.*SQRT(U*ZA-ZA**2)
   TP=LT*(V*20.268)
   DF=1.0+1.34*EXP(-1.27*TP)
   GO TO (70,80),NTYP
70 OMEGA=CI*8*D*SQRT(ZT/HT)/FV
   OMEGAC=OMEGA*DF/1.6
   GO TO 50
80 OMEGB=CI*(R*D)**1.5*(ZT/HT)/FV
   OMEGAS=OMEGB*DF/1.6
50 RETURN
   END

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SLDG2160
SLDG2161
SLDG2162
SLDG2163
SLDG2164
SLDG2165
SLDG2166
SLDG2167
SLDG2168
SLDG2169
SLDG2170
SLDG2171
SLDG2172
SLDG2173
SLDG2174
SLDG2175
SLDG2176
SLDG2177
SLDG2178
SLDG2179
SLDG2180
SLDG2181
SLDG2182
SLDG2183
SLDG2184
SLDG2185
SLDG2186
SLDG2187
SLDG2188
SLDG2189
SLDG2190
SLDG2191
SLDG2192
SLDG2193
SLDG2194
SLDG2195
SLDG2196
SLDG2197
SLDG2198
SLDG2199

$1BFTC DRAGX M94,XR7,DECK
SUBROUTINE DRAG(NTYP,FD,NTAND,Z1P)
*****
C SUBROUTINE DRAG CALCULATES WHEEL-SOIL DRAG FOR EITHER A SINGLE
C OR TANDEM WHEEL FOR EITHER CLAY OR SANDY SOIL.
C
C ROUTINE REQUIREMENTS-
C OMEGAS AND/OR OMEGAS FROM ROUTINGESINK-TROUGH COMMON
C FV FROM ROUTINE FVG
C ROUTINE LOOK FOR TABLE LOOK-UP(TABLE VALUES THROUGH COMMON)
C
C CALLING SEQUENCE
C CALL DRAG(N,D,NT,Z)
C WHERE-
C N=TYPE SOIL-1 FOR CLAY,2 FOR SAND
C D=CALCULATED DRAG
C NT=NUMBER TANDEM-WHEEL SETS
C Z=FIRST PASS DYNAMIC SINKAGE
C *****
COMMON/SOIL/CI,B,D,FV,ZI,HT,G,V,ZS,OMEGAC,OMEGAS,RHUS
COMMON/TABLES/XCI(11),YCLT(11),XVOVP(4),YCDI(4),XFDN(20),VDFN(20),
1XFFVM(20),YDFM(20),XVEL(20),YTH(20)
COMMON/STAR/MU1P,MU2P
REAL MU1P,MU2P
GO TO (10,20),NTYP
10 MU1P=0.4072/(OMEGAC-0.8713)-0.0206
IF(MU1P.LE.0.03) MU1P=0.03
IF(NTAND.EQ.0) GO TO 25
MU2P=MU1P
GO TO 25
20 MU1P=0.6490/(OMEGAS-2.2222)+0.0366
IF(MU1P.LE.0.03) MU1P=0.03
IF(NTAND.EQ.0) GO TO 25
MU2P=0.7085/(OMEGAS-2.1739)+0.0195
CI=0.5*(1.66781/12.)*2*RHOS*B
AT=2.3*ZI*SGRT(B*D)
GO TO (26,27),NTYP
26 CALL LOOK (CI,CLT,XCI,YCLT,11)
GO TO 28
27 G=CI*B/2.

```

28	CALL LOOK(G,CLT,XCI,YCLT,11)	SLDG2200
	VP=SQRT(288.*FV/(AT*RHOS*CLT))	SLDG2201
	VOVP=V*1.689/VP	SLDG2202
	CALL LOOK (VOVP,CUI,XVOVP,YCDI,4)	SLDG2203
	IF(NTAND.EQ.0) GO TO 40	SLDG2204
	IF(NTYP.GT.1) GO TO 30	SLDG2205
	TWF=0.4	SLDG2206
	GO TO 35	SLDG2207
30	TWF=1.0	SLDG2208
35	FS=C1*CDI*Z1P*V*V	SLDG2209
	FD=(MUIP+MU2P)*FV+FS*(1.+TWF)	SLDG2210
	GO TO 45	SLDG2211
40	FD=MUIP*FV+C1*CDI*Z1P*V*V	SLDG2212
45	RETURN	SLDG2213
	END	SLDG2214

```

$1BFTC TOTDGX M94,XK7,DECK
SUBROUTINE TOTDG (NTYP,TDAG)
C*****
C ROUTINE CALCULATES TOTAL SOIL DRAG FOR NOSE WHEEL AND MAIN WHEELS
C NTYP=TYPE SOIL
C TDAG=TOTAL DRAG IN POUNDS
C*****
COMMON/SOIL/CI,B,D,FV,ZT,HT,G,V,ZS,OMEGAC,OMEGAS,RHOS
COMMON/GEAR/DWB,DCG,WNG,WMG,NTANDN,N,BN,DN,BM,DM,HTN,HTM
COMMON/SINK1/Z1N,Z2N,Z1M,Z2M
COMMON/DRAG1/FDNOSE,FDMAIN
COMMON/STAR1/MU1P,MU2P
COMMON/STAR1/MUN,MUM
REAL MU1P,MU2P,MUN,MUM
CALL FVG(FVNGS,FVMGS,V)
FV=FVNGS
B=BV
D=DN
HT=HTN
CALL DEFL(FV,ZT,N,1)
CALL SINK(NTYP,Z1N,Z2N,NTANDN)
CALL DRAG(NTYP,FON,NTANDN,Z1N)
MUN=MU1P
IF(NTANDN.EQ.0) GO TO 10
TANDN=NTANDN
FDNOSE=FON*WNG
GO TO 15
10 FDNOSE=FON*WNG
15 FV=FVMGS
B=BM
D=DN
HT=HTM
CALL DEFL(FV,ZT,N,2)
CALL SINK(NTYP,Z1M,Z2M,NTAND)
CALL DRAG(NTYP,FDM,NTANDN,Z1M)
MUM=MU2P
IF(NTANDN.EQ.0) GO TO 20
TANDN=NTANDN
FDMAIN=FDM*WMG*2.
GO TO 30
20 FDMAIN=FDM*WMG*2.
30 TDAG=FDNOSE+FDMAIN
RETURN
END

```

SLDG2215  
 SLDG2216  
 SLDG2217  
 SLDG2218  
 SLDG2219  
 SLDG2220  
 SLDG2221  
 SLDG2222  
 SLDG2223  
 SLDG2224  
 SLDG2225  
 SLDG2226  
 SLDG2227  
 SLDG2228  
 SLDG2229  
 SLDG2230  
 SLDG2231  
 SLDG2232  
 SLDG2233  
 SLDG2234  
 SLDG2235  
 SLDG2236  
 SLDG2237  
 SLDG2238  
 SLDG2239  
 SLDG2240  
 SLDG2241  
 SLDG2242  
 SLDG2243  
 SLDG2244  
 SLDG2245  
 SLDG2246  
 SLDG2247  
 SLDG2248  
 SLDG2249  
 SLDG2250  
 SLDG2251  
 SLDG2252  
 SLDG2253  
 SLDG2254  
 SLDG2255  
 SLDG2256  
 SLDG2257  
 SLDG2258

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SLDG2259
SLDG2260
SLDG2261
SLDG2262
SLDG2263
SLDG2264
SLDG2265
SLDG2266
SLDG2267
SLDG2268
SLDG2269
SLDG2270
SLDG2271
SLDG2272
SLDG2273
SLDG2274
SLDG2275
SLDG2276
SLDG2277
SLDG2278
SLDG2279
SLDG2280
SLDG2281

$IBFTC DEFLX  M94,XR7,DECK
SUBROUTINE DEFL(X,Y,N,K)
C*****
C SUBROUTINE DEFL CALCULATES TIRE DEFLECTION USING ROUTINE LOOK
C AND AN ARRAY OF TIRE-DEFLECTION VS VERTICAL LOAD VALUES
C
C CALLING SEQUENCE-
C CALL DEFL(X,Y,N,K)
C WHERE-
C X=VERTICAL TIRE LOAD
C Y=RESULTANT DEFLECTION
C N=SIZE OF ARRAYS
C K=1 FOR NOSE-WHEEL TIRE,2 FOR MAIN-GEAR TIRE
C*****
COMMON/TABLES/XCI(11),YCLT(11),XVOVP(4),YCDI(4),XFVN(20),YDFN(20),
1XFVM(20),YDFM(20),XVEL(20),YTH(20)
GO TO (10,20),K
10 CALL LOOK (X,Y,XFVN,YDFN,N)
RETURN
20 CALL LOOK (X,Y,XFVM,YDFM,N)
RETURN
END

```

```

$1BFTC FVXXX M94,XR7,DECK SLDG2282
SUBROUTINE FVG (FVNGS,FVMGS,V) SLDG2283
***** SLDG2284
C ROUTINE CALCULATES WEIGHT DISTRIBUTION FOR CG VARIATION AND
C THE RESULTANT LOAD ON NOSE AND MAIN GEAR STRUTS SLDG2285
C (LIFT MINUS WEIGHT) SLDG2286
C FVNGS=VERTICAL LOAD ON NOSE GEAR STRUT SLDG2287
C FVMGS=VERTICAL LOAD ON MAIN GEAR STRUT SLDG2288
C V=VELOCITY SLDG2289
***** SLDG2290
COMMON/CRAFT/W,AW,CL,CD,SIG SLDG2291
COMMON/GEAR/DWB,DCG,WNG,NTANDN,N,BN,DN,BM,DM,HTN,HTM SLDG2292
COMMON/WML/FVCG SLDG2293
REAL L SLDG2294
L=CL*SIG*V*V*AW/295.371 SLDG2295
FVCG=W-L SLDG2296
FVNGS=FVCG*DCG/(DWB*WNG) SLDG2297
FVMGS=FVCG*(DWB-DCG)/(DWB*2.*WNG) SLDG2298
RETURN SLDG2299
END SLDG2300
SLDG2301

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SLDG2302
SLDG2303
SLDG2304
SLDG2305
SLDG2306
SLDG2307
SLDG2308
SLDG2309
SLDG2310
SLDG2311
SLDG2312
SLDG2313
SLDG2314
SLDG2315
SLDG2316
SLDG2317
SLDG2318
SLDG2319
SLDG2320
SLDG2321
SLDG2322
SLDG2323
SLDG2324
SLDG2325
SLDG2326
SLDG2327
SLDG2328

$18FTC LOXXX M94,XR7,DECK
SUBROUTINE LOOK(X,Y,XX,YY,N)
*****
SUBROUTINE LOOK GIVES ONE DIMENSIONAL TABLE LOOK-UP USING LINEAR
INTERPOLATION
CALLING SEQUENCE-
CALL LOOK(X,Y,XX,YY,N)
WHERE-
X=INDEPENDENT VARIABLE
Y=INTERPOLATED RESULT
XX=ARRAY OF INDEPENDENT VARIABLES
YY=RESULT ARRAY
N=DIMENSION OF XX AND YY
*****
DIMENSION XX(N),YY(N)
IF(X.LT.XX(1).OR.X.GT.XX(N)) GO TO 30
DO 10 I=1,N
IF(X-XX(I))20,15,10
CONTINUE
Y=YY(I)
RETURN
Y=YY(I-1)+((YY(I)-YY(I-1))*(X-XX(I-1)))/(XX(I)-XX(I-1))
RETURN
WRITE(6,35) X
FORMAT(1H0,25HVALUE OUTSIDE TABLE X = ,E15.8)
STOP
END

```



COMPUTER PROGRAM

SOLDC



22	READ(5,20) CII,DCI,CIMAX,VI,DELV,VMAX CI=CII V=VI	SOLDG041 SOLDG042 SOLDG043 SOLDG044 SOLDG045 SOLDG046 SOLDG047 SOLDG048 SOLDG049 SOLDG050 SOLDG051 SOLDG052 SOLDG053 SOLDG054
23	CALL DEFL(W,ZI,N,1) CALL SINK(NTYP,Z1,Z2,NTAND,0) CALL DRAG(NTYP,FD,NTAND,Z1) IF(NTAND.EQ.0) GO TO 26 TAND=NTAND DR=FD/(W*2.*TAND) GO TO 27	SOLDG055 SOLDG056 SOLDG057 SOLDG058 SOLDG059 SOLDG060
26	DR=FD/W	
27	WRITE(6,40) B8	
40	FORMAT(1H,/,9X,19A6/) WRITE(6,41) A(NTYP),CI	
41	FORMAT(1H 30X,47H SOIL DRAG FOR A SINGLE SET OF TIRES ROLLING ON ,ASOLDG055 16,4H SOIL/31X,21H WITH A CONE INDEX OF ,F4.0,27H AND CONSTANT TAXI VSOLDG056 2ELOCITY/)	SOLDG056 SOLDG057 SOLDG058 SOLDG059 SOLDG060
42	WRITE(6,42) B8 FORMAT(9X,19A6/)/)	SOLDG061 SOLDG062 SOLDG063 SOLDG064 SOLDG065 SOLDG066 SOLDG067 SOLDG068 SOLDG069 SOLDG070 SOLDG071 SOLDG072 SOLDG073
30	WRITE(6,30)W,V,B,D,Z1,FD,NTYP,NTAND,DR,MUIP,MU2P FORMAT(1H ,5X,10HWEIGHT = ,E14.7,3X,11HVELOCITY = ,E14.7,3X,13HTI IRE WIDTH = ,E14.7,3X,11HTIRE DIA = ,E14.7//6X,10HSINKAGE = ,E14.7,3X,13HTI 23X,11H DRAG = ,E14.7,3X,13H OIL TYPE = ,I2,15X,11HTANDEM = ,E14.7,3X,13H MU STAR1 = ,E14.7,3X,13H MU STAR2 312//6X,10HFD/FV = ,E14.7,3X,11H MU STAR1 = ,E14.7,3X,13H MU STAR2 4 = ,E14.7) V=V+DELV IF(V.GT.VMAX) GO TO 35 GO TO 23	
35	CI=CI+DCI IF(CI.GT.CIMAX) GO TO 5 V=VI GO TO 23 END	

```

$IBFTC SINKX M94,XR7,DECK
SUBROUTINE SINK (NTYP,Z1P,Z2P,NTAND)
C*****
C ROUTINE CALCULATES SOIL SINKAGE FOR FIRST AND SECOND PASSES
C OF A TIRE ROLLING ON CLAY OR SANDY SOIL
C
C CALLING SEQUENCE-
C CALL SINK (NTYP,Z1P,Z2P,NTAND)
C WHERE-
C NTYP=SOIL TYPE (CLAY=1,SAND=2)
C Z1P=FIRST PASS SINKAGE
C Z2P=SECOND PASS SINKAGE
C NTAND=NUMBER OF TANDEM WHEEL SETS
C THE FOLLOWING IS REQUIRED THROUGH COMMON
C COMMON/SOIL/CI,B,D,FV,ZT,HT,G,V,ZS,OMEGAC,OMEGAS,RHOS
C*****
COMMON/SOIL/CI,B,D,FV,ZT,HT,G,V,ZS,OMEGAC,OMEGAS,RHOS
REAL LT
Z2P=0.0
INT=1
1 ZA=ZS+ZT
  LF=2.*SQRT(D*ZA-ZA**2)
  IF(V.EQ.0.) GO TO 2
  TP=LT/(V*1.689*12.)
  GO TO 5
2 DF=1.
  GO TO 6
5 DF=1.0+1.34*EXP(-1.27*TP)
6 GO TO (10,20),NTYP
10 OMEGA=CI*B*D*SQRT(ZT/HT)/FV
  OMEGAC=OMEGA*DF/1.6
  Z1P= (0.1208/(OMEGAC-0.9468)-0.0095)*D
  IF(Z1P.LE.0.1) GO TO 32
  GO TO 25
20 OMEGB=CI*(B*D)**1.5*(ZT/HT)/FV
  OMEGAS=OMEGB*DF/1.6
  Z1P=(0.3439/(OMEGAS-0.6239)-0.0018)*D
  IF(Z1P.LE.0.1) GO TO 32
25 EPS=ABS(Z1P-ZS)

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SOLDG074  
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SOLDG130  
SOLDG131  
SOLDG132  
SOLDG133  
SOLDG134

```

IF(EPS-.01.LT.0.) RETURN
INT=INT+1
IF(INT.GT.100) GO TO 27
ZS=Z1P
GO TO 1
WRITE(6,28)
26  FORMAT(1H0 35HSINKAGE ITERATIONS GREATER THAN 100)
STOP
32  Z1P=0.1
    ZA=.1+ZT
    LT=2.*SQRT(D*ZA-ZA**2)
    TP=LT/(V*20.268)
    DF=1.0+1.34*EXP(-1.27*TP)
    GO TO (70,80),NTYP
70  OMEGA=CI*B*D*SQRT(ZT/HT)/FV
    OMEGAC=OMEGA*DF/1.6
    GO TO 50
80  OMEGB=CI*(B*D)**1.5*(ZT/HT)/FV
    OMEGAS=OMEGB*DF/1.6
50  RETURN
    END

```

```

$IBFTC DRAGX   M94,XR7,DECK
  SUBROUTINE DRAG(NTYP,FD,NTAND,Z1P)
*****
C  SUBROUTINE DRAG CALCULATES WHEEL-SOIL DRAG FOR EITHER A SINGLE
C  OR TANDEM WHEEL FOR EITHER CLAY OR SANDY SOIL.
C
C  ROUTINE REQUIREMENTS-
C  OMEGAS AND/OR OMEGAS FROM ROUTINGESINK-TROUGH COMMON
C  FV FROM ROUTINE FVG
C  ROUTINE LOOK FOR TABLE LOOK-UP(TABLE VALUES THROUGH COMMON)
C
C  CALLING SEQUENCE
C  CALL DRAG(N,D,NT,Z)
C  WHERE-
C      N=TYPE SOIL-1 FOR CLAY,2 FOR SAND
C      D=CALCULATED DRAG
C      NT=NUMBER TANDEM-WHEEL SETS
C      Z=FIRST PASS DYNAMIC SINKAGE
*****
COMMON/SOIL/CI,B,D,FV,ZT,HT,G,V,ZS,OMEGAC,OMEGAS,RHOS
COMMON/TABLES/XCI(11),YCLT(11),XVOVP(4),YCDI(4),XFDN(20),YDFN(20),
1XFVM(20),YDFM(20),XVEL(20),YTH(20)
COMMON/STAR/MUIP,MU2P
REAL MUIP,MU2P
GO TO (10,20),NTYP
10  MUIP=0.4072/(OMEGAC-0.8713)-0.0206
   IF(MUIP.LE.0.03) MUIP=0.03
   IF(NTAND.EQ.0) GO TO 25
   MU2P=MUIP
   GO TO 25
20  MUIP=0.6490/(OMEGAS-2.2222)+0.0366
   IF(MUIP.LE.0.03) MUIP=0.03
   IF(NTAND.EQ.0) GO TO 25
   MU2P=0.7085/(OMEGAS-2.1739)+0.0195
   CI=0.5*(1.68781/12.)*2*RHOS*B
   AT=2.3*ZT*SQRT(8*D)
   GO TO (26,27),NTYP
25  CALL LOOK (CI,CLT,XCI,YCLT,11)
   GO TO 28
26  G=CI*B/2.
27

```

SOLDG175  
SOLDG176  
SOLDG177  
SOLDG178  
SOLDG179  
SOLDG180  
SOLDG181  
SOLDG182  
SOLDG183  
SOLDG184  
SOLDG185  
SOLDG186  
SOLDG187  
SOLDG188  
SOLDG189

```

28      CALL LOOK(G,CLT,XCI,YCLT,11)
        VP=SQRT(288.*FV/(AT*RHOS*CLT))
        VOVP=V*1.689/VP
        CALL LOOK (VOVP,CDI,XVOVP,YCDI,4)
        IF(NIAND.EQ.0) GO TO 40
        IF(NTYP.GT.1) GO TO 30
        TW=0.4
        GO TO 35
30      TW=1.0
35      FS=CI*CDI*Z1P*V*V
        FD=(MUIP+MU2P)*FV+FS*(1.+TW)
        GO TO 45
40      FD=MUIP*FV+CI*CDI*Z1P*V*V
45      RETURN
        END

```

```

$1BFTC DEFLX  M94,XR7,DECK                                SOLDG190
SUBROUTINE DEFL(X,Y,N,K)                                SOLDG191
C*****                                                    SOLDG192
C SUBROUTINE DEFL CALCULATES TIRE DEFLECTION USING ROUTINE LOOK
C AND AN ARRAY OF TIRE-DEFLECTION VS VERTICAL LOAD VALUES
C
C CALLING SEQUENCE-
C CALL DEFL(X,Y,N,K)
C WHERE-
C X=VERTICAL TIRE LOAD
C Y=RESULTANT DEFLECTION
C N=SIZE OF ARRAYS
C K=1 FOR NOSE-WHEEL TIRE,2 FOR MAIN-GEAR TIRE
C
C*****
COMMON/TABLES/XCI(11),YCLT(11),XVOVP(4),YCDI(4),XFVN(20),YDFN(20),
1XFVM(20),YDFM(20),XVEL(20),YTH(20)
GO TO (10,20),K
10 CALL LOOK (X,Y,XFVN,YDFN,N)
RETURN
20 CALL LOOK (X,Y,XFVM,YDFM,N)
RETURN
END
SOLDG203
SOLDG204
SOLDG205
SOLDG206
SOLDG207
SOLDG208
SOLDG209
SOLDG210
SOLDG211
SOLDG212

```

```

$1BFTC LQXXX   M94,XR7,DECK
SUBROUTINE LOOK(X,Y,XX,YY,N)
*****
C SUBROUTINE LOOK GIVES ONE DIMENSIONAL TABLE LOOK-UP USING LINEAR
C INTERPOLATION
C CALLING SEQUENCE-
C CALL LOOK(X,Y,XX,YY,N)
C WHERE-
C X=INDEPENDENT VARIABLE
C Y=INTERPOLATED RESULT
C XX=ARRAY OF INDEPENDENT VARIABLES
C YY=RESULT ARRAY
C N=DIMENSION OF XX AND YY
*****
DIMENSION XX(N),YY(N)
IF(X.LT.XX(1).OR.X.GT.XX(N)) GO TO 30
DO 10 I=1,N
IF(X-XX(I))20,15,10
10 CONTINUE
15 Y=YY(I)
RETURN
20 Y=YY(I-1)+((YY(I)-YY(I-1))*(X-XX(I-1)))/(XX(I)-XX(I-1))
RETURN
30 WRITE(6,35) X
35 FORMAT(1H0,25HVALUE OUTSIDE TABLE X = ,E15.8)
STOP
END

```

```

$IBFTC BLOCKX M94,XR7,DECK
BLOCK DATA
C*****
C BLOCK DATA GIVES SOIL LIFT AND DRAG CURVES
C      XCI=CONE INDEX VALUES
C      YCLT=LIFT COEFFICIENT VALUES (FOR 36 TO 1 CI TO C8R)
C      XVOVP=VELOCITY RATIO, VELOCITY OVER PLANING VELOCITY
C      YCDI=IMPENGEMENT DRAG COEFFICIENT VALUES
C*****
COMMON/TABLES/XCI(1),YCLT(11),XVOVP(4),YCDI(4),XFMN(20),YDFN(20),
1XFMN(20),YDFM(20),XVEL(20),YTH(20)
DATA XCI/0.0,72.,96.,110.,145.,180.,220.,240.,260.,280.,2000./
DATA YCLT/0.216,0.216,0.218,0.24,0.335,0.44,0.58,0.635,0.675,0.7,0.7,
1.7/
DATA XVOVP/0.0,1.0, 1.5,9.0/
DATA YCDI/1.68,1.68,0.03,0.03/
END
SOLDG240
SOLDG241
SOLDG242
SOLDG243
SOLDG244
SOLDG245
SOLDG246
SOLDG247
SOLDG248
SOLDG249
SOLDG250
SOLDG251
SOLDG252
SOLDG253
SOLDG254
SOLDG255
SOLDG256

```

## APPENDIX B

### SAMPLE INPUT FOR SOIL DRAG PROGRAMS

1. Discussion - This Appendix gives the input data setup for a sample problem which will be solved using each of the three programs. The problem is to determine the performance capability of the Boeing 367-80 aircraft at 150,000 lb. gross weight operating on clay soil with a Cone Index of 90. The problem will be solved assuming three levels of data completeness. The first (Problem A) assumes that all data given in Appendix D is known and that the takeoff distance time history on clay and on paved surface is required in order to determine the increase in takeoff distance which will result from operation on the clay soil. The second problem (Problem B) will assume that no engine thrust data is available. This, of course, precludes the time history and the associated takeoff distance but will give the same soil sinkage and drag which was obtained from the more complete problem. The final case (Problem C) assumes that only the gross weight of the vehicle and the number and type of tires used on the vehicle are available. This solution neglects aerodynamic effects, and therefore results in slightly higher drag loads than the other program but is conservative for design and has the advantage of requiring a minimum of input data. Data and deck setup for each problem will now be covered as a separate paragraph.

2. Problem A - Using the data of Appendix D for the 367-80 aircraft and the computer program TAKOFF given in Appendix A, calculate a takeoff time history for the aircraft at 150,000 lb. gross weight operating on a clay soil with a cone index of 90, and a takeoff time history on a paved runway.

The input data consists of seven distinct sections as shown in Figure 109. The details of each section are as follows:

#### Section 1 (one card) - Aerodynamic Data

Card Column	Format	Variable Name	Definition
1-12	F12.4	AW	Wing Area (Ft <sup>2</sup> )
13-24	F12.4	CL	Takeoff Lift Coefficient
25-36	F12.4	CD	Takeoff Drag Coefficient
37-48	F12.4	SIG	Atmospheric Density Ratio
49-60	I12	K	Number of Values Each of Thrust and Velocity

## Section 2 - Thrust Data

Card Column	Format	Variable Name	Definition
1-72	6F12.4	XVEL(I)	K Values of Velocity (Knots)
1-72	6F12.4	YTH(1)	K Values of Single Engine Thrust Corresponding to XVEL (1) Values

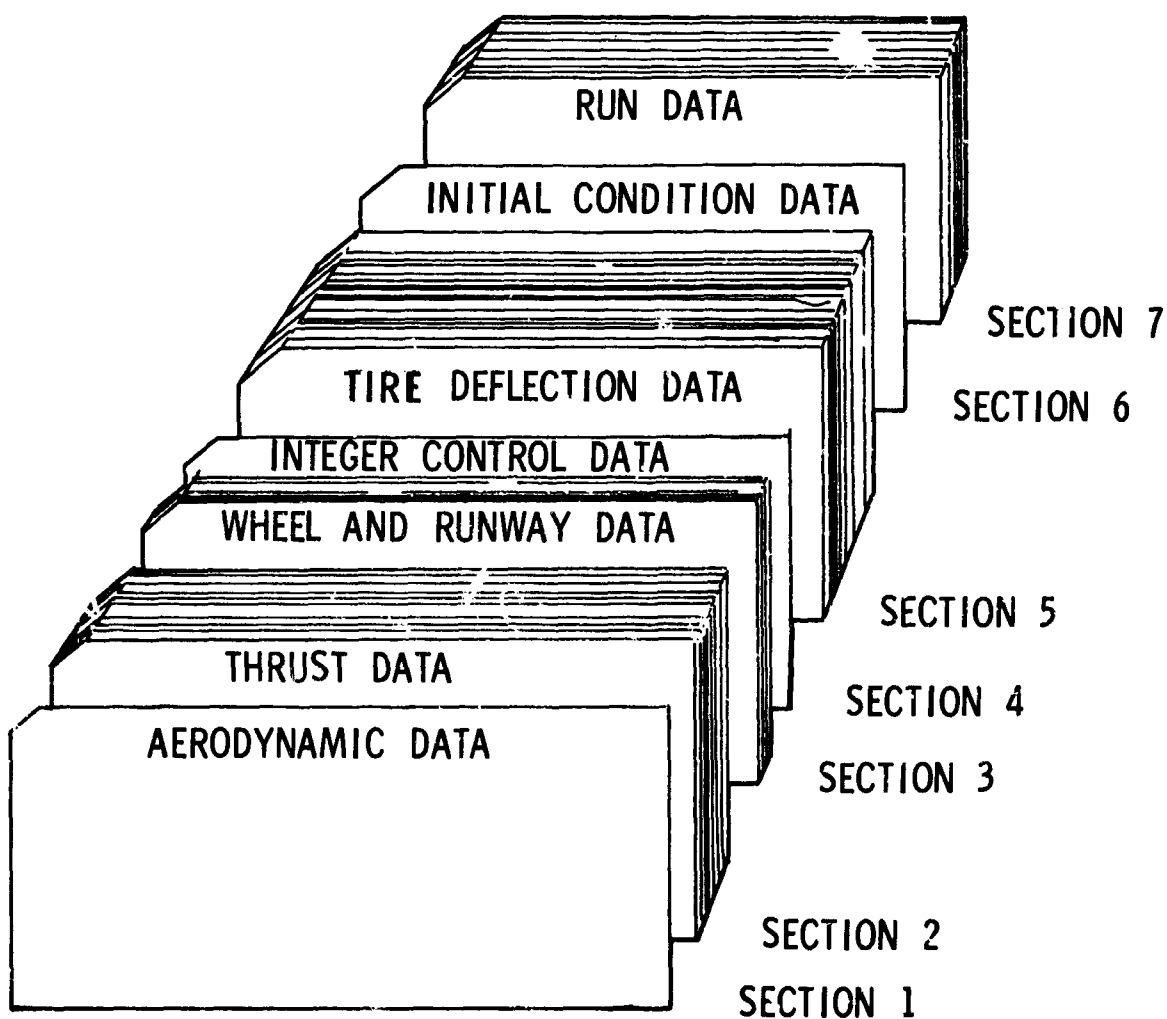


Figure 109 Input Data Deck for Program TAKOFF

### Section 3 (2 Cards) - Wheel and Runway Data

#### Card 1

Card Column	Format	Variable Name	Definition
1-12	F12.4	DWB	Distance Between Nose and Main Gear Struts (Ft)
13-24	F12.4	WNG	Number of Nose Wheels Per Strut (one strut allowed)
25-36	F12.4	WMG	Number of Main Gear Wheels per Side
37-48	F12.4	BN	Width of Nose Gear Tire (In)
49-60	F12.4	DN	Diameter of Nose Gear Tire (In)
61-72	F12.4	BM	Width of Main Gear Tire (In)

#### Card 2

Card Column	Format	Variable Name	Definition
1-12	F12.4	DM	Diameter of Main Gear (In)
13-24	F12.4	HTN	Nose Gear Tire Section Height (In)
25-36	F12.4	HTM	Main Gear Tire Section Height (In)
37-48	F12.4	RHOS	Soil (usually 2.6) Density (Lb/Sec <sup>2</sup> /Ft <sup>4</sup> )
49-60	F12.4	SLOPE	Runway Slope (Rad)

### Section 4 (1 Card) - Integer Control Data

Card Column	Format	Variable Name	Definition
1-12	I12	NTANDN	Number of Nose Gear Tandem Wheel Sets
13-24	I12	NTANDM	Number of Main Gear Tandem Wheel Sets Per Side
25-36	I12	NTYP	Soil Type (-1 for Clay, -2 for Sand)
37-48	I12	NENGs	Number of Engines
49-60	I12	N	Number of Pairs of Load and Deflection Values to be Read for Nose and Main Gear Tire Deflection Curves

### Section 5 - Tire Deflection Curves

Card Column	Format	Variable Name	Definition
1-72	6F12.4	XFVN(I)	N Values of Nose Gear Vertical Load (Lb)
1-72	6F12.4	YDFN(I)	N Values of Nose Gear Tire Deflection Corresponding to the XFVN(I) Load (In)
1-72	6F12.4	XFVM(I)	N Values of Main Gear Vertical Load (Lb)
1-72	6F12.4	YDFM(I)	N Values of Main Gear Tire Deflection Corresponding to the XFVM(I) Loads (In)

### Section 6 - Initial Conditions Data

Card Column	Format	Variable Name	Definition
1-12	F12.4	SO	Initial Distance for Takeoff Integration (Ft) Usually = 0
13-24	F12.4	VO	Initial Velocity for Takeoff Integration (Ft/Sec) (Usually 0 for Paved Runs and 2 or 3 for Soil Runs)
25-36	F12.4	AO	Initial Acceleration for Takeoff Integration (Ft/Sec <sup>2</sup> ) Usually = 0
37-48	F12.4	DT	Integration Interval (Sec) (Usually 0.1 or 0.01)
49-60	F12.4	ZS	Initial Soil Sinkage Estimate (In) (Normal Value = 0.5)

### Section 7 - Run Data

Card Column	Format	Variable Name	Definition
1 - 12	F12.4	CI	Cone Index for Clay Soil (PSI) Can be Zero if Paved or Sand Runs are Being Made
13-24	F12.4	G	Cone Index for Sand (PSI/In) Can be Zero if Paved br Clay Runs are being Made
25-36	F12.4	RRC	Paved Runway Friction Coefficient. Must be Zero if Clay or Sand runs are desired
37-48	F12.4	W	Total Gross Weight of Vehicle (Lb)
49-60	F12.4	DCG	CG Location (Ft Forward of Main Gear Strut)
61-72	F12.4	VT0	Velocity Required for Takeoff (Ft/Sec)

For additional time history runs on the same soil type, only the run data card need be changed to reflect a new soil strength or gross weight condition. If the soil type is to be changed, however, the Section 4 card must be changed to reflect the desired NTYP. Tables 3 and 4 give a listing of the data used for the paved surface runs and the clay soil runs respectively. Notice that the only difference is that the RRC value has been given the non-zero value of 0.02 and the initial velocity has been set to zero to obtain the paved takeoff time history. The results of this problem are given in Appendix C.

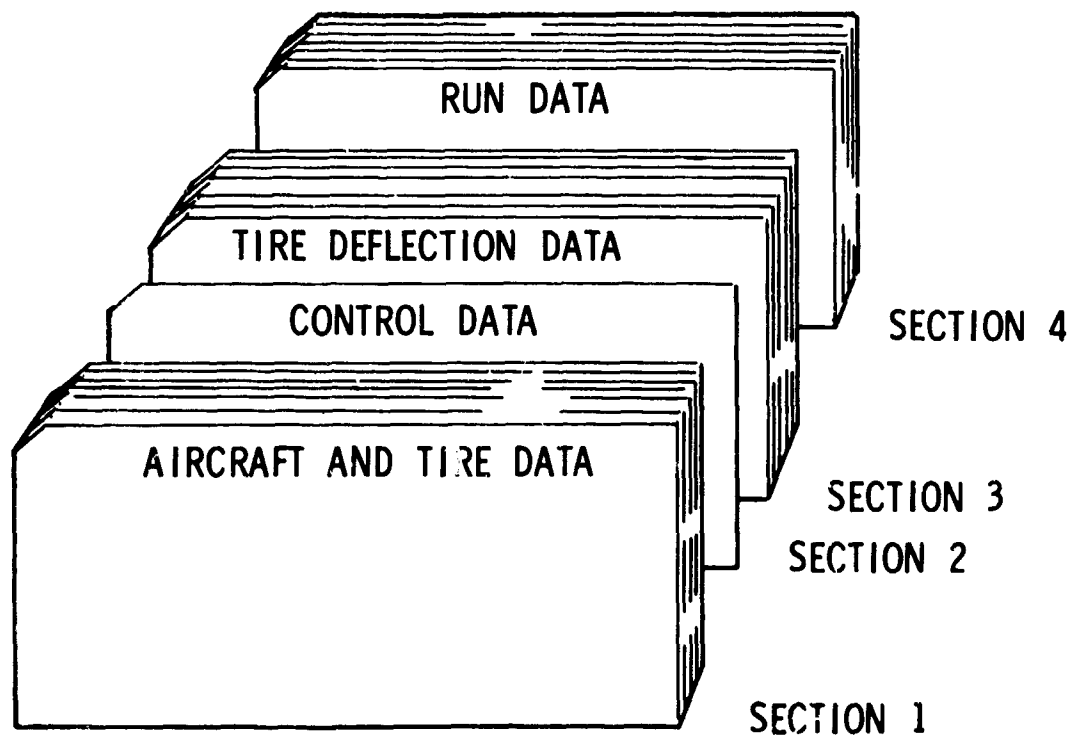
3. Problem B - Using the data of Appendix B for the 367-80 aircraft and the computer program SOLDG2 given in Appendix A, compute the soil sinkage and drag ratio (total drag divided by total vertical load - lift minus weight) for a number of taxi velocities assuming sufficient thrust to maintain constant speed. The aircraft is operated on clay soil with cone index of 90 and gross weight of 150,000 lbs.

The input data consists of four sections as shown in Figure 110. Details of each parameter are given below:

Section 1 (3 Cards) - Aircraft and Tire Data

Card 1

Card Column	Format	Variable Name	Definition
1-12	F12.4	W	Vehicle Weight (Lb)
13-24	F12.4	ZS	Initial Estimate of Soil Sinkage (In) (Usually 0.5)
25-36	F12.4	BN	Diameter of Nose Gear Tire (In)
37-48	F12.4	HTN	Nose Tire Section Height (In)
49-60	I12	N	Number of Pairs of Nose and Main Tire Deflection Curves to be Read



**Figure 110 Input Data Deck for Program SOLDG2 and SOLDG**

Card 2

Card Column	Format	Variable Name	Definition
1-12	F12.4	AW	Wing Area (Ft <sup>2</sup> )
13-24	F12.4	BM	Width of Main Gear Tire (In)
25-36	F12.4	DM	Diameter of Main Gear Tire (In)
37-48	F12.4	HTM	Main Gear Tire Section Height (In)
49-60	F12.4	CL	Takeoff Lift Coefficient
61-72	F12.4	CD	Takeoff Drag Coefficient

Card 3

Card Column	Format	Variable Name	Definition
1-12	F12.4	DWB	Distance Between Nose and Main Gear Struts (Ft)
13-24	F12.4	DCG	CG Location (Ft Forward of Main Gear Strut)
25-36	F14.4	WNG	Number of Nose Wheels Per Strut (one strut allowed)
37-48	F12.4	WMG	Number of Main Gear Wheels Per Side
49-60	F12.4	RHOS	Soil (usually 2.6) Density (lb/sec <sup>2</sup> /ft <sup>4</sup> )
61-72	F12.4	SIG	Atmospheric Density Ratio

## Section 2 (1 Card) - Control Data

Card Column	Format	Variable Name	Definition
1-12	I12	NTYP	Soil Type (= 1 for Clay, =2 for Sand)
13-24	I12	NTANDN	Number of Nose Gear Tandem Wheel Sets
25-36	I12	NTANDM	Number of Main Gear Tandem Wheel Sets Per Side

### Section 3    Tire Deflection Data

Card Column	Format	Variable Name	Definition
1-72	6F12.4	XNVN(I)	N Values of Nose Tire Vertical Load (Lb)
1-72	6F12.4	YDFN(I)	N Values of Nose Tire Deflection Corresponding to Load XNVN(I) (In)
1-72	6F12.4	XFVM(I)	N Values of Main Tire Vertical Load (Lb)
1-72	6F12.4	YDFM(I)	N Values of Main Tire Deflection Corresponding to Load XFVM(I) (In)

### Section 4 (1 Card Per Run) Run Data

Card Column	Format	Variable Name	Definition
1-12	F12.4	CII	Initial Value of Soil Strength Either CI or G Depending on Value of NTYP
13-24	F12.4	DCI	Incremental Soil Strength
25-36	F12.4	CIMAX	Maximum Value of Soil Strength Desired
37-48	F12.4	VI	Initial Taxi Velocity (Knots)
49-60	F12.4	DELV	Incremental Taxi Velocity (Knots)
61-72	F12.4	VMAX	Maximum Taxi Velocity Desired (Knots)

Using the run data of Section 4, the program will determine drag ratio and sinkage for each taxi velocity for a particular soil strength and will then increment soil strength until all soil strengths have been processed. Table 5 gives a listing of the data used in the problem. Results are contained in Appendix C.

4. Problem C - Using only the tire, vehicle weight and soil data from Appendix D, calculate the soil sinkage and drag ratio values corresponding to a range of constant taxi velocities. Use computer program SOLDG from Appendix A and assume clay soil with cone index of 90 and vehicle weight of 150,000 lbs.

The input data for SOLDG consists of four sections as shown in Figure 110. Card format for each parameter is shown below:

Section 1 (1 Card) - Vehicle and Tire Data

Card Column	Format	Variable Name	Definition
1-12	F12.4	W	Wheel Load for One Wheel of One Main Gear Strut (Lb)
13-24	F12.4	ZS	Initial Estimate of Soil Sinkage (In) (Usually 0.5)
25-36	F12.4	B	Main Gear Tire Width (In)
37-48	F12.4	D	Main Gear Tire Diameter (In)
49-60	F12.4	HT	Main Gear Tire Section Height (In)
61-72	F12.4	RHOS	Soil Density (Lb/Sec <sup>2</sup> /Ft <sup>4</sup> )

Section 2 (1 Card) - Control Data

Card Column	Format	Variable Name	Definition
1-12	I12	N	Number of Pairs of Main Gear Tire Deflection Values to be Read
13-24	I12	NTYP	Soil Type ( = 1 if Clay, = 2 if Sand)
25-36	I12	NTAND	Number of Main Gear Tandem Wheel Sets Per Strut

Section 3 - Tire Deflection Data

Card Column	Format	Variable Name	Definition
1-72	6F12.4	XFVN(I)	N Values of Main Tire Load (Lb)
1-72	6F12.4	YDFN(I)	N Values of Tire Deflection Which Correspond to the XFVN(I) Load (In)

Section 4 (1 Card) - Run Data

Card Column	Format	Variable Name	Definition
1-12	F12.4	CII	Initial Value of Soil Strength Either Clay (CI) or Sand (G)
13-24	F12.4	DCI	Incremental Soil Strength
25-36	F12.4	CIMAX	Maximum Value of Soil Strength Desired
37-48	F12.4	VI	Initial Taxi Velocity (Knots)
49-60	F12.4	DELV	Incremental Taxi Velocity (Knots)
61-72	F12.4	VMAX	Maximum Value of Velocity Desired (Knots)

Section 4 data will cause the program to calculate soil drag and sinkage for various velocities for a constant soil strength and then increment soil strength until all strength values have been processed. Table 6 lists the input data for Problem C. The solution to Problem C is given in Appendix C.

TABLE 3

## SAMPLE INPUT DATA FOR PROBLEM A - CLAY AIRFIELD

2821.	0.641	0.048	1.		9
-20.	0.	4.	10.	20.	30.
40.	70.	150.			
9000.	9000.	11000.	12000.	13000.	13500.
13750.	14000.	14000.			
44.	4.	8.	10.65	30.7	15.0
45.	6.6	10.75	2.6	0.	
	0	4	1	4	5
0.	1250.	2500.	3750.	7500.	
0.	.6	1.2	1.7	3.7	
0.	2500.	5000.	10000.	20000.	
0.0	1.2	2.15	3.75	6.9	
0.	3.0	0.	.1	.5	
90.	0.	0.	150000.	2.36	219.57

TABLE 4

## SAMPLE INPUT DATA FOR PROBLEM A - PAVED AIRFIELD

2821.	0.641	0.048	1.		9
-20.	0.	4.	10.	20.	30.
40.	70.	150.			
9000.	9000.	11000.	12000.	13000.	13500.
13750.	14000.	14000.			
44.	4.	8.	10.65	30.7	15.0
45.	6.6	10.75	2.6	0.	
	0	4	1	4	5
0.	1250.	2500.	3750.	7500.	
0.	.6	1.2	1.7	3.7	
0.	2500.	5000.	10000.	20000.	
0.0	1.2	2.15	3.75	6.9	
0.	0.0	0.	.1	.5	
0.	0.	0.0	150000.	2.36	219.57

TABLE 5

## SAMPLE INPUT DATA FOR PROBLEM B

150000.	.5	10.65	30.7	6.6	5
2821.	15.	45.	10.75	0.641	
44.	2.30	4.	8.	2.6	
	1	3	4		
	1250.	2500.	3750.	7500.	
0.	.6	1.2	1.7	3.7	
0.	2500.	5000.	10000.	20000.	
0.	1.2	2.15	3.75	6.9	
90.	10.	100.	5.	15.	
				120.	

0.048  
1.

TABLE 6

## SAMPLE INPUT DATA FOR PROBLEM C

8872.14	.5	15.	45.	10.75	2.6
	5	1	1		
0.	2500.	5000.	10000.	20000.	
0.	1.2	2.15	3.75	6.9	
90.	10.	100.	5.	15.	
				120.	

## APPENDIX C

### SAMPLE OUTPUT FROM SOIL DRAG PROGRAM

1. Discussion - Results from the three problems presented in Appendix B are shown as Tables 7, 8, 9 and 10. Table 7 gives the takeoff time history on soil and Table 8, the takeoff time history on a paved surface thus fulfilling the requirements of Problem A except for the percent increase in takeoff distance which is merely  $PI = \frac{\text{total takeoff distance on soil} - \text{total takeoff distance on pavement}}{\text{total takeoff distance on pavement}} \times 100$  or in the actual numbers of Problem A:

$$PI = \frac{3633 - 2240}{2240} \times 100 \quad (23)$$
$$= 62\%$$

Table 9 gives the results for Problem B. Note that for any speed, the two results are identical. Finally, Table 10 gives results for Problem C. A drag ratio velocity history for each program has been plotted as Figure 111 and shows the effect of simplification on the final results. Notice that although the SOLDG program varies from the results of SOLDG2 and TAKOFF, it varies in a conservative manner from a design point of view.

2. Tables of Results - The following tables are computer results from Problems A, B and C presented in Appendix B.

<u>Table</u>	<u>Problem</u>	<u>Program</u>	<u>Page</u>
7	A	TAKOFF	191
8	A	TAKOFF	198
9	B	SOLDG2	203
10	C	SOLDG	206

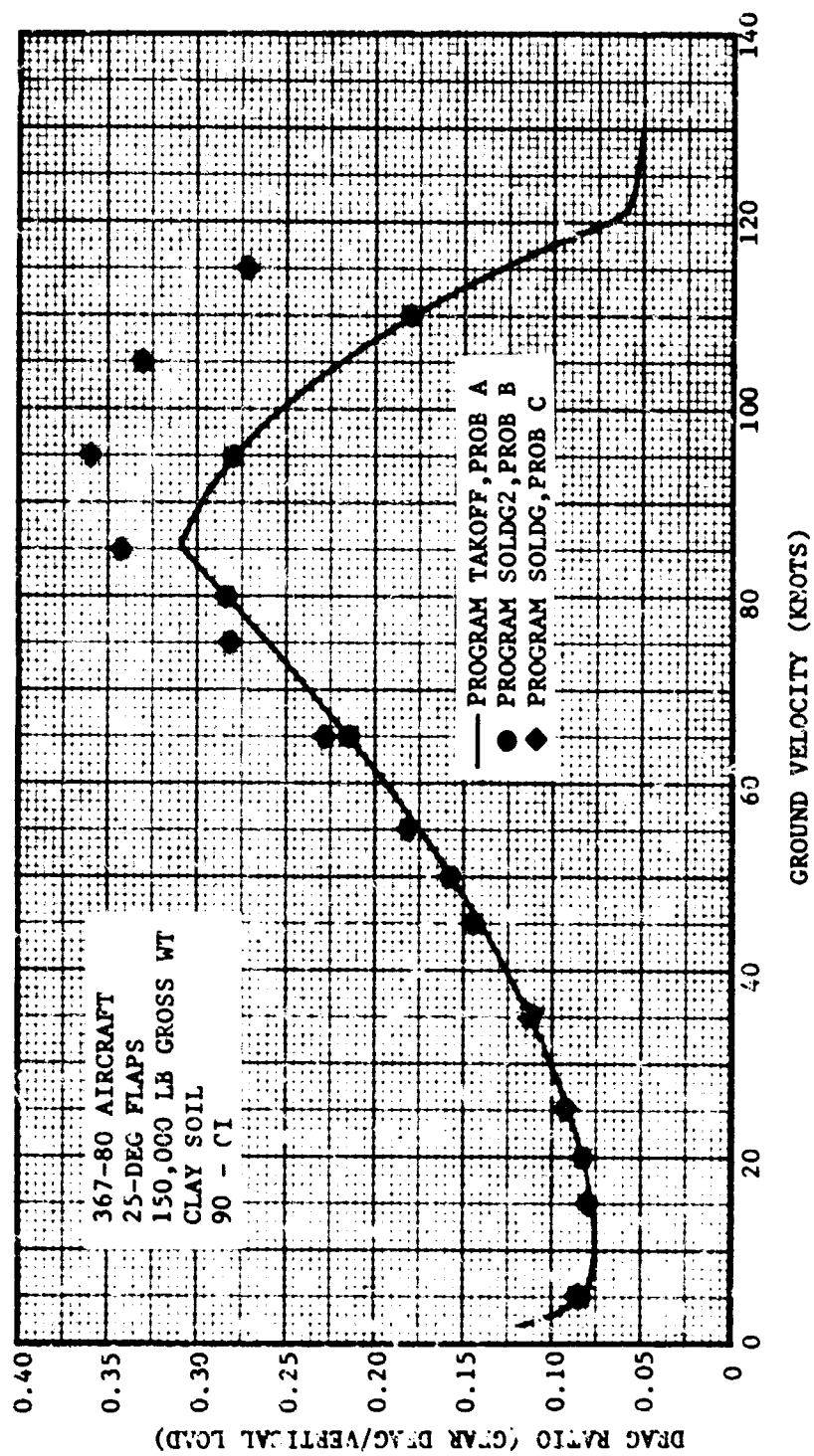


Figure 111. Comparison of Sample Problem Results Using Landing Gear Drag Ratio as a Function of Ground Velocity

TABLE 7

PROBLEM A - RESULTS FOR SOIL AIRFIELD

TAKEOFF PERFORMANCE OF AN AIRCRAFT OPERATING FROM A  
CLAY FIELD WITH A CONE INDEX OF 90. AND INITIAL VELOCITY OF 3.0 FT/SEC.

WEIGHT	=	0.150000E 06	WING AREA=	0.282100E 04	W NOSE TIRE=	0.106500E 02	D NOSE TIRE=	0.307000E 02			
CL (TO)	=	0.641000E 00	CD (TO)	=	0.480000E-01	W MAIN TIRE=	0.150000E 02	D MAIN TIRE=	0.450000E 02		
ALT (SIG)	=	0.100000E 01	SLOPE	=	0.	N TANDEM	=	0	M TANDEM	=	4
VTOLREQD)	=	0.219570E 03	RND SOIL	=	0.260000E 01	WHEEL BASE	=	0.440000E 02	CG LOCATION=	0.236000E 01	

TABLE 7 (Cont'd)

TIME SEC	ADDOCT FT/SEC**2	ADDT FT/SEC	ADDT KNOTS	DISTANCE FT	N GEAR DRAG-LB	M GEAR DRAG-LB	DRAW RATIO	N TIRE SINKAGE	M TIRE SINKAGE	OMEGA
0.10	0.	1.02	0.	0.	0.	0.	0.	0.	0.	0.
0.20	4.86	1.47	2.35	0.32	398.86	1735.32	0.1162	0.353	1.496	3.77
0.30	5.23	3.97	2.35	0.69	383.91	15952.48	0.1589	0.335	1.387	3.94
0.40	5.55	4.51	2.67	1.12	372.10	15381.31	0.1331	0.320	1.300	4.09
0.50	5.85	5.08	3.01	1.60	362.76	14377.46	0.0983	0.308	1.230	4.23
0.60	6.13	5.66	3.36	2.14	355.36	13804.62	0.0944	0.298	1.172	4.35
0.70	6.19	6.10	3.73	2.73	349.53	13334.52	0.0913	0.290	1.124	4.45
0.80	6.60	6.96	4.12	3.40	344.97	12945.79	0.0887	0.283	1.084	4.54
0.90	6.73	7.62	4.51	4.13	341.50	12625.77	0.0865	0.278	1.051	4.62
1.00	6.84	8.30	4.91	4.92	338.93	12360.85	0.0847	0.273	1.023	4.69
1.10	6.95	8.99	5.32	5.79	337.13	12140.03	0.0833	0.268	0.999	4.76
1.20	7.05	9.69	5.74	6.72	335.96	11954.99	0.0820	0.265	0.978	4.81
1.30	7.14	10.40	6.16	7.72	335.50	11799.39	0.0810	0.262	0.960	4.86
1.40	7.23	11.12	6.58	8.80	335.36	11668.38	0.0802	0.259	0.944	4.91
1.50	7.31	11.85	7.01	9.95	335.67	11558.16	0.0795	0.256	0.930	4.95
1.60	7.39	12.58	7.45	11.17	336.37	11465.73	0.0789	0.254	0.918	4.99
1.70	7.47	13.32	7.89	12.47	337.45	11388.71	0.0784	0.252	0.907	5.02
1.80	7.55	14.07	8.33	13.83	338.88	11325.17	0.0777	0.250	0.897	5.05
1.90	7.62	14.83	8.78	15.28	340.62	11273.55	0.0777	0.249	0.888	5.08
2.00	7.70	15.60	9.24	16.80	342.68	11232.57	0.0774	0.247	0.879	5.11
2.10	7.77	16.37	9.69	18.40	345.04	11199.56	0.0773	0.246	0.872	5.13
2.20	7.83	17.15	10.16	20.08	347.68	11177.03	0.0772	0.244	0.865	5.15
2.30	7.87	17.94	10.62	21.83	350.59	11162.46	0.0771	0.243	0.858	5.17
2.40	7.91	18.73	11.09	23.64	353.75	11155.21	0.0771	0.242	0.852	5.19
2.50	7.95	19.52	11.56	25.58	357.17	11154.69	0.0772	0.241	0.847	5.21
2.60	7.98	20.32	12.03	27.57	360.84	11160.41	0.0773	0.240	0.842	5.23
2.70	8.02	21.12	12.50	29.64	364.74	11171.93	0.0774	0.239	0.837	5.25
2.80	8.06	21.92	12.98	31.79	368.87	11188.91	0.0776	0.238	0.832	5.26
2.90	8.09	22.73	13.46	34.02	373.24	11211.02	0.0778	0.237	0.828	5.28
3.00	8.12	23.54	13.94	36.34	377.83	11237.99	0.0781	0.236	0.824	5.29
3.10	8.15	24.35	14.42	38.73	382.64	11269.58	0.0783	0.236	0.820	5.30
3.20	8.19	25.17	14.90	41.21	387.68	11305.55	0.0787	0.235	0.817	5.32
3.30	8.22	25.99	15.39	43.76	392.93	11345.82	0.0790	0.234	0.813	5.33
3.40	8.25	26.81	15.87	46.40	398.40	11390.11	0.0794	0.233	0.810	5.34
3.50	8.28	27.64	16.36	49.13	404.08	11438.31	0.0798	0.233	0.807	5.35
3.60	8.30	28.47	16.85	51.93	409.97	11490.30	0.0803	0.232	0.804	5.36
3.70	8.33	29.30	17.35	54.82	416.08	11545.96	0.0807	0.231	0.801	5.37
3.80	8.36	30.13	17.84	57.79	422.39	11605.18	0.0812	0.231	0.798	5.38
3.90	8.39	30.97	18.34	60.85	428.91	11667.86	0.0818	0.230	0.795	5.39
4.00	8.41	31.81	18.83	63.99	435.63	11733.92	0.0823	0.230	0.793	5.40
4.10	8.43	32.65	19.33	67.21	442.56	11803.27	0.0829	0.229	0.790	5.41
4.20	8.46	33.50	19.83	70.52	449.69	11875.85	0.0835	0.228	0.788	5.42
4.30	8.47	34.34	20.33	73.91	457.02	11951.53	0.0841	0.228	0.785	5.43
4.40	8.47	35.19	20.83	77.38	464.53	12030.11	0.0848	0.227	0.783	5.44
4.50	8.47	36.04	21.34	80.95	472.21	12111.49	0.0855	0.227	0.781	5.45
4.60	8.47	36.88	21.84	84.59	480.07	12195.60	0.0862	0.226	0.779	5.45
4.70	8.47	37.73	22.34	88.32	488.10	12282.35	0.0869	0.226	0.776	5.46
4.80	8.46	38.58	22.84	92.14	496.30	12371.69	0.0877	0.225	0.774	5.47
4.90	8.46	39.42	23.34	96.04	504.67	12463.55	0.0884	0.225	0.772	5.48
5.00	8.46	40.27	23.84	100.02	513.20	12557.86	0.0892	0.224	0.770	5.49
5.10	8.46	41.11	24.34	104.09	521.89	12654.56	0.0900	0.224	0.768	5.49
5.20	8.45	41.96	24.84	108.24	530.74	12753.59	0.0909	0.223	0.766	5.50
5.30	8.45	42.80	25.34	112.48	539.74	12854.90	0.0917	0.223	0.764	5.51
5.40	8.44	43.65	25.84	116.81	548.89	12958.43	0.0926	0.222	0.762	5.52
5.50	8.44	44.49	26.34	121.21	558.19	13064.12	0.0935	0.222	0.760	5.52
5.60	8.43	45.34	26.84	125.70	567.63	13171.93	0.0944	0.221	0.759	5.53
5.70	8.42	46.18	27.34	130.28	577.22	13281.79	0.0953	0.221	0.757	5.54
5.80	8.41	47.02	27.84	134.94	586.95	13393.67	0.0962	0.220	0.755	5.54
5.90	8.41	47.86	28.34	139.68	596.81	13507.50	0.0972	0.220	0.753	5.55
6.00	8.40	48.70	28.83	144.51	606.80	13623.24	0.0982	0.219	0.751	5.56

TABLE 7 (Cont'd)

6.06	8.39	49.54	29.33	149.42	616.93	13740.84	0.0992	0.219	0.750	5.57
6.10	8.38	50.36	29.83	154.42	627.18	13860.25	0.1002	0.218	0.748	5.57
6.20	8.34	51.22	30.32	159.50	637.55	13981.40	0.1013	0.218	0.746	5.58
6.30	8.34	52.05	30.82	164.66	648.01	14104.11	0.1023	0.217	0.744	5.59
6.40	8.32	52.88	31.31	169.91	658.61	14228.33	0.1034	0.217	0.742	5.59
6.50	8.30	53.72	31.80	175.24	669.30	14354.01	0.1045	0.216	0.741	5.60
6.60	8.28	54.54	32.29	180.65	680.07	14481.08	0.1056	0.216	0.739	5.61
6.70	8.25	55.37	32.78	186.15	690.94	14609.51	0.1067	0.215	0.737	5.61
6.80	8.23	56.20	33.27	191.73	701.90	14739.24	0.1078	0.215	0.736	5.62
6.90	8.21	57.02	33.76	197.39	712.94	14870.22	0.1090	0.214	0.734	5.63
7.00	8.19	57.84	34.24	203.13	724.07	15002.40	0.1101	0.214	0.732	5.63
7.10	8.16	58.65	34.73	208.95	735.27	15135.74	0.1113	0.213	0.730	5.64
7.20	8.14	59.47	35.21	214.86	746.54	15270.18	0.1125	0.213	0.729	5.65
7.30	8.11	60.28	35.69	220.85	757.89	15405.68	0.1137	0.212	0.727	5.66
7.40	8.09	61.09	36.17	226.92	769.30	15542.20	0.1149	0.212	0.725	5.66
7.50	8.06	61.90	36.65	233.07	780.78	15679.67	0.1161	0.211	0.724	5.67
7.60	8.04	62.70	37.13	239.30	792.31	15818.07	0.1173	0.211	0.722	5.68
7.70	8.01	63.51	37.60	245.61	803.90	15957.34	0.1186	0.210	0.720	5.68
7.80	7.99	64.31	38.07	252.00	815.54	16097.44	0.1198	0.209	0.719	5.69
7.90	7.96	65.10	38.55	258.47	827.23	16238.32	0.1211	0.209	0.717	5.70
8.00	7.93	65.90	39.02	265.02	839.97	16379.94	0.1224	0.208	0.715	5.71
8.10	7.91	66.69	39.49	271.65	850.75	16522.26	0.1237	0.208	0.714	5.71
8.20	7.88	67.48	39.95	278.36	862.57	16665.24	0.1250	0.207	0.712	5.72
8.30	7.85	68.27	40.42	285.14	874.41	16808.77	0.1263	0.207	0.710	5.72
8.40	7.81	69.05	40.88	292.01	886.28	16952.76	0.1276	0.206	0.709	5.73
8.50	7.78	69.83	41.34	298.95	898.17	17097.15	0.1290	0.206	0.707	5.74
8.60	7.74	70.60	41.80	305.98	910.08	17241.89	0.1303	0.205	0.705	5.75
8.70	7.71	71.38	42.26	313.07	921.99	17386.97	0.1317	0.205	0.704	5.75
8.80	7.68	72.15	42.72	320.25	933.91	17532.31	0.1330	0.204	0.702	5.76
8.90	7.64	72.91	43.17	327.50	945.84	17677.90	0.1344	0.204	0.700	5.77
9.00	7.61	73.68	43.62	334.83	957.77	17823.69	0.1358	0.203	0.699	5.77
9.10	7.57	74.43	44.07	342.24	969.70	17969.64	0.1371	0.203	0.697	5.78
9.20	7.54	75.19	44.52	349.72	981.63	18115.72	0.1385	0.202	0.695	5.79
9.30	7.50	75.94	44.96	357.28	993.54	18261.88	0.1399	0.202	0.693	5.80
9.40	7.47	76.69	45.41	364.91	1005.45	18408.09	0.1413	0.201	0.692	5.80
9.50	7.43	77.44	45.85	372.61	1017.35	18554.71	0.1427	0.200	0.690	5.81
9.60	7.40	78.18	46.29	380.40	1029.23	18700.51	0.1441	0.200	0.688	5.82
9.70	7.36	78.92	46.72	388.25	1041.08	18846.46	0.1456	0.199	0.687	5.83
9.80	7.33	79.65	47.16	396.18	1052.92	18992.72	0.1470	0.199	0.685	5.83
9.90	7.30	80.38	47.59	404.16	1064.74	19138.66	0.1484	0.198	0.683	5.84
10.00	7.26	81.11	48.02	412.25	1076.52	19284.44	0.1498	0.198	0.682	5.85
10.10	7.23	81.83	48.45	420.40	1088.28	19430.03	0.1513	0.197	0.680	5.86
10.20	7.19	82.55	48.88	428.62	1100.01	19575.41	0.1527	0.197	0.678	5.86
10.30	7.16	83.27	49.30	436.91	1111.70	19720.55	0.1542	0.196	0.677	5.87
10.40	7.12	83.99	49.73	445.28	1123.35	19865.40	0.1556	0.195	0.675	5.88
10.50	7.09	84.70	50.15	453.71	1134.97	20009.95	0.1571	0.195	0.673	5.89
10.60	7.05	85.40	50.56	462.21	1146.54	20154.17	0.1585	0.194	0.672	5.89
10.70	7.02	86.11	50.98	470.79	1158.07	20298.02	0.1600	0.194	0.670	5.90
10.80	6.98	86.81	51.40	479.44	1169.56	20441.49	0.1615	0.193	0.668	5.91
10.90	6.95	87.50	51.81	488.15	1180.99	20584.55	0.1630	0.193	0.666	5.92
11.00	6.91	88.20	52.22	496.94	1192.38	20727.16	0.1644	0.192	0.665	5.92
11.10	6.88	88.89	52.63	505.79	1203.71	20869.31	0.1659	0.191	0.663	5.93
11.20	6.85	89.57	53.03	514.71	1214.99	21010.98	0.1674	0.191	0.661	5.94
11.30	6.81	90.26	53.44	523.70	1226.22	21152.13	0.1689	0.190	0.660	5.95
11.40	6.78	90.94	53.84	532.76	1237.38	21292.74	0.1704	0.189	0.658	5.95
11.50	6.74	91.62	54.24	541.89	1248.49	21432.80	0.1718	0.189	0.656	5.96
11.60	6.71	92.28	54.64	551.09	1259.53	21572.28	0.1733	0.189	0.655	5.97
11.70	6.68	92.95	55.03	560.35	1270.51	21711.16	0.1748	0.188	0.653	5.98
11.80	6.64	93.62	55.43	569.68	1281.43	21849.42	0.1763	0.187	0.651	5.99
11.90	6.61	94.28	55.82	579.07	1292.28	21987.04	0.1778	0.187	0.650	5.99
12.00	6.58	94.94	56.21	588.53	1303.06	22124.50	0.1793	0.186	0.648	6.00
12.10	6.54	95.60	56.60	598.06	1313.77	22260.28	0.1806	0.186	0.646	6.01

TABLE 7 (Cont'd)

12.20	6.51	96.25	56.99	627.95	1324.41	22395.87	0.1823	0.195	0.444	6.02
12.30	6.48	96.90	57.37	617.31	1334.98	22530.74	0.1838	0.185	0.443	6.03
12.40	6.45	97.75	57.75	627.03	1457.47	22664.88	0.1853	0.184	0.441	6.04
12.50	6.41	98.19	58.13	636.82	1355.89	22798.28	0.1868	0.183	0.439	6.05
12.60	6.38	98.83	58.51	646.67	1366.23	22932.91	0.1883	0.183	0.438	6.06
12.70	6.35	99.47	58.89	656.56	1376.69	23067.76	0.1898	0.182	0.436	6.07
12.80	6.32	100.10	59.27	666.54	1386.67	23193.82	0.1913	0.182	0.434	6.08
12.90	6.29	100.73	59.64	676.60	1396.78	23324.07	0.1928	0.181	0.432	6.09
13.00	6.25	101.36	60.01	686.71	1406.90	23453.50	0.1943	0.180	0.431	6.10
13.10	6.22	101.98	60.38	696.88	1416.74	23582.09	0.1958	0.180	0.429	6.11
13.20	6.19	102.60	60.75	707.10	1426.59	23709.84	0.1973	0.179	0.427	6.12
13.30	6.16	103.22	61.11	717.43	1436.36	23836.72	0.1988	0.179	0.426	6.13
13.40	6.13	103.83	61.48	727.75	1446.05	23962.74	0.2003	0.178	0.424	6.14
13.50	6.10	104.44	61.84	738.16	1455.15	24087.86	0.2018	0.177	0.422	6.15
13.60	6.07	105.05	62.20	748.64	1465.14	24212.10	0.2033	0.177	0.421	6.16
13.70	6.04	105.66	62.56	759.17	1474.58	24335.43	0.2048	0.176	0.419	6.17
13.80	6.01	106.26	62.91	769.77	1483.91	24457.84	0.2063	0.175	0.417	6.18
13.90	5.98	106.86	63.27	780.42	1493.16	24579.33	0.2078	0.175	0.415	6.19
14.00	5.95	107.46	63.62	791.14	1502.31	24699.88	0.2092	0.175	0.414	6.20
14.10	5.92	108.05	63.97	801.91	1511.37	24819.49	0.2107	0.174	0.412	6.21
14.20	5.89	108.64	64.32	812.75	1520.49	24938.14	0.2122	0.173	0.410	6.22
14.30	5.84	109.23	64.67	823.64	1529.60	25055.83	0.2137	0.173	0.409	6.23
14.40	5.83	109.81	65.02	834.59	1539.00	25172.55	0.2152	0.172	0.407	6.24
14.50	5.80	110.39	65.36	845.60	1548.11	25288.30	0.2167	0.172	0.405	6.25
14.60	5.77	110.97	65.70	856.67	1557.13	25403.05	0.2182	0.171	0.403	6.26
14.70	5.75	111.55	66.04	867.80	1566.04	25516.82	0.2197	0.170	0.402	6.27
14.80	5.72	112.12	66.38	878.98	1574.86	25629.58	0.2211	0.170	0.400	6.28
14.90	5.69	112.69	66.72	890.22	1583.59	25741.35	0.2226	0.169	0.398	6.29
15.00	5.66	113.26	67.06	901.52	1592.21	25852.10	0.2241	0.169	0.397	6.30
15.10	5.63	113.82	67.39	912.87	1600.73	25961.83	0.2256	0.168	0.395	6.31
15.20	5.61	114.39	67.72	924.28	1609.16	26070.54	0.2270	0.167	0.393	6.32
15.30	5.58	114.94	68.05	935.75	1617.48	26178.22	0.2285	0.167	0.392	6.33
15.40	5.55	115.50	68.38	947.27	1625.70	26284.89	0.2300	0.166	0.390	6.34
15.50	5.53	116.06	68.71	958.85	1633.83	26390.51	0.2314	0.166	0.388	6.35
15.60	5.50	116.61	69.04	970.48	1641.85	26495.08	0.2329	0.165	0.386	6.36
15.70	5.47	117.16	69.36	982.17	1649.77	26598.62	0.2343	0.164	0.385	6.37
15.80	5.45	117.70	69.69	993.91	1657.59	26701.11	0.2358	0.164	0.383	6.38
15.90	5.42	118.25	70.01	1005.71	1665.31	26802.55	0.2372	0.163	0.381	6.39
16.00	5.40	118.79	70.33	1017.56	1672.92	26902.91	0.2387	0.163	0.380	6.40
16.10	5.37	119.32	70.65	1029.47	1680.43	27002.17	0.2401	0.162	0.378	6.41
16.20	5.34	119.86	70.96	1041.43	1687.83	27100.33	0.2416	0.161	0.376	6.42
16.30	5.31	120.39	71.28	1053.44	1695.13	27197.39	0.2430	0.161	0.374	6.43
16.40	5.29	120.92	71.59	1065.51	1702.32	27293.35	0.2444	0.160	0.373	6.44
16.50	5.26	121.45	71.91	1077.63	1709.40	27388.20	0.2459	0.160	0.371	6.45
16.60	5.24	121.98	72.22	1089.80	1716.38	27481.95	0.2473	0.159	0.369	6.46
16.70	5.21	122.50	72.53	1102.02	1723.25	27574.59	0.2487	0.158	0.368	6.47
16.80	5.18	123.02	72.83	1114.30	1730.02	27666.13	0.2501	0.158	0.366	6.48
16.90	5.16	123.53	73.14	1126.62	1736.68	27756.55	0.2515	0.157	0.364	6.49
17.00	5.13	124.05	73.45	1139.00	1743.24	27845.88	0.2529	0.157	0.363	6.50
17.10	5.11	124.56	73.75	1151.43	1749.68	27934.09	0.2544	0.156	0.361	6.51
17.20	5.09	125.07	74.05	1163.92	1756.03	28021.20	0.2558	0.155	0.359	6.52
17.30	5.06	125.58	74.35	1176.45	1762.26	28107.20	0.2571	0.155	0.358	6.53
17.40	5.04	126.08	74.65	1189.03	1768.39	28192.10	0.2585	0.154	0.356	6.54
17.50	5.01	126.59	74.95	1201.64	1774.42	28275.89	0.2599	0.154	0.355	6.55
17.60	4.99	127.09	75.24	1214.35	1780.35	28358.57	0.2613	0.153	0.352	6.56
17.70	4.97	127.58	75.54	1227.08	1786.15	28440.14	0.2627	0.152	0.351	6.57
17.80	4.94	128.08	75.83	1239.86	1791.86	28520.60	0.2641	0.152	0.349	6.58
17.90	4.92	128.57	76.12	1252.70	1797.46	28600.01	0.2654	0.151	0.347	6.59
18.00	4.90	129.04	76.41	1265.58	1802.95	28678.28	0.2668	0.151	0.346	6.60
18.10	4.88	129.55	76.70	1278.51	1808.34	28755.46	0.2681	0.150	0.344	6.61
18.20	4.86	130.04	76.99	1291.49	1813.67	28831.53	0.2695	0.149	0.342	6.62
18.30	4.83	130.52	77.28	1304.52	1818.67	28906.50	0.2709	0.149	0.341	6.63

TABLE 7 (Cont'd)

18.40	4.81	131.01	77.56	1317.59	1823.88	28980.38	0.2722	0.148	0.539	6.57
18.50	4.79	131.49	77.85	1330.72	1828.85	29053.16	0.2735	0.148	0.537	6.58
18.60	4.77	131.96	78.13	1343.89	1833.72	29124.85	0.2749	0.147	0.536	6.59
18.70	4.75	132.44	78.41	1357.11	1838.48	29195.44	0.2762	0.146	0.534	6.60
18.80	4.73	132.91	78.69	1370.38	1843.13	29264.94	0.2775	0.146	0.532	6.61
18.90	4.71	133.39	78.97	1383.69	1847.68	29333.35	0.2789	0.145	0.531	6.62
19.00	4.69	133.86	79.25	1397.06	1852.13	29400.67	0.2802	0.145	0.529	6.63
19.10	4.67	134.32	79.53	1410.47	1856.47	29466.90	0.2815	0.144	0.527	6.64
19.20	4.65	134.79	79.81	1423.92	1860.71	29532.05	0.2828	0.143	0.526	6.65
19.30	4.63	135.26	80.08	1437.42	1864.84	29596.11	0.2841	0.143	0.524	6.66
19.40	4.61	135.72	80.35	1450.97	1868.87	29659.09	0.2854	0.142	0.522	6.67
19.50	4.60	136.18	80.63	1464.57	1872.79	29720.98	0.2867	0.142	0.520	6.68
19.60	4.58	136.64	80.90	1478.21	1876.61	29781.80	0.2880	0.141	0.519	6.69
19.70	4.56	137.09	81.17	1491.85	1880.33	29841.53	0.2893	0.141	0.517	6.70
19.80	4.54	137.55	81.44	1505.63	1883.94	29900.19	0.2905	0.140	0.515	6.71
19.90	4.52	138.00	81.71	1519.40	1887.45	29957.77	0.2918	0.139	0.514	6.72
20.00	4.51	138.45	81.97	1533.23	1890.85	30014.27	0.2931	0.139	0.512	6.73
20.10	4.49	138.90	82.24	1547.09	1894.16	30069.70	0.2943	0.138	0.510	6.74
20.20	4.47	139.35	82.51	1561.01	1897.35	30124.06	0.2956	0.138	0.509	6.75
20.30	4.46	139.80	82.77	1574.96	1900.45	30177.35	0.2969	0.137	0.507	6.76
20.40	4.44	140.24	83.03	1588.97	1903.44	30229.57	0.2981	0.136	0.505	6.77
20.50	4.43	140.69	83.30	1603.01	1906.33	30280.71	0.2993	0.136	0.504	6.78
20.60	4.41	141.13	83.56	1617.10	1909.11	30330.80	0.3006	0.135	0.502	6.79
20.70	4.39	141.57	83.82	1631.24	1911.79	30379.81	0.3018	0.135	0.500	6.81
20.80	4.38	142.01	84.08	1645.42	1914.37	30427.75	0.3030	0.134	0.499	6.82
20.90	4.36	142.44	84.34	1659.64	1916.85	30474.63	0.3043	0.133	0.497	6.83
21.00	4.35	142.88	84.59	1673.91	1919.22	30520.45	0.3055	0.133	0.495	6.84
21.10	4.34	143.31	84.85	1688.22	1921.49	30565.20	0.3067	0.132	0.494	6.85
21.20	4.32	143.75	85.11	1702.57	1923.65	30608.88	0.3079	0.132	0.492	6.86
21.30	4.31	144.18	85.36	1716.96	1925.71	30651.51	0.3091	0.131	0.490	6.87
21.40	4.31	144.61	85.62	1731.40	1927.67	30693.94	0.3098	0.130	0.489	6.88
21.50	4.33	145.04	85.87	1745.89	1929.54	30736.10	0.3094	0.130	0.487	6.89
21.60	4.35	145.47	86.13	1760.41	1931.32	30777.02	0.3090	0.129	0.485	6.90
21.70	4.37	145.91	86.39	1774.98	1933.00	30817.64	0.3085	0.129	0.484	6.91
21.80	4.40	146.35	86.65	1789.59	1934.59	30857.91	0.3081	0.128	0.482	6.92
21.90	4.42	146.79	86.91	1804.25	1936.08	30897.79	0.3076	0.127	0.480	6.94
22.00	4.45	147.23	87.17	1818.95	1937.47	30937.43	0.3071	0.127	0.478	6.95
22.10	4.48	147.68	87.44	1833.70	1938.75	30976.83	0.3065	0.126	0.477	6.96
22.20	4.50	148.13	87.70	1848.49	1939.93	31016.08	0.3060	0.125	0.475	6.97
22.30	4.53	148.58	87.97	1863.32	1941.00	31055.18	0.3054	0.125	0.473	6.98
22.40	4.56	149.04	88.24	1878.21	1941.95	31094.03	0.3048	0.124	0.471	7.00
22.50	4.58	149.49	88.51	1893.13	1942.79	31132.64	0.3041	0.123	0.469	7.01
22.60	4.61	149.95	88.78	1908.10	1943.50	31171.01	0.3035	0.123	0.467	7.02
22.70	4.64	150.41	89.06	1923.12	1944.13	31209.07	0.3028	0.122	0.465	7.03
22.80	4.67	150.89	89.33	1938.19	1944.56	31246.80	0.3020	0.121	0.464	7.05
22.90	4.71	151.35	89.61	1953.30	1944.89	31284.21	0.3013	0.121	0.462	7.06
23.00	4.74	151.82	89.89	1968.46	1945.08	31321.31	0.3005	0.120	0.460	7.07
23.10	4.77	152.30	90.17	1983.66	1945.13	31358.11	0.2997	0.119	0.458	7.09
23.20	4.80	152.78	90.45	1998.92	1945.04	31394.64	0.2988	0.118	0.456	7.10
23.30	4.84	153.26	90.74	2014.22	1944.80	31431.41	0.2979	0.118	0.454	7.12
23.40	4.87	153.74	91.03	2029.57	1944.40	31468.31	0.2970	0.117	0.452	7.13
23.50	4.91	154.23	91.32	2044.97	1943.84	31505.32	0.2961	0.116	0.450	7.14
23.60	4.94	154.72	91.61	2060.41	1943.11	31542.41	0.2951	0.116	0.447	7.16
23.70	4.98	155.22	91.90	2075.91	1942.21	31579.64	0.2941	0.115	0.445	7.17
23.80	5.02	155.72	92.20	2091.46	1941.13	31616.94	0.2930	0.114	0.443	7.19
23.90	5.06	156.23	92.50	2107.06	1939.88	31654.33	0.2919	0.113	0.441	7.21
24.00	5.10	156.73	92.80	2122.70	1938.43	31691.74	0.2908	0.112	0.439	7.22
24.10	5.14	157.24	93.10	2138.40	1936.78	31729.04	0.2896	0.112	0.437	7.24
24.20	5.18	157.76	93.40	2154.15	1934.93	31766.21	0.2883	0.111	0.434	7.25
24.30	5.22	158.28	93.71	2169.95	1932.87	31803.35	0.2871	0.110	0.432	7.27
24.40	5.27	158.81	94.02	2185.81	1930.59	31840.44	0.2858	0.109	0.430	7.29
24.50	5.31	159.33	94.34	2201.72	1928.08	31877.49	0.2844	0.108	0.427	7.30

TABLE 7 (Cont'd)

24.40	5.34	159.87	94.65	2217.48	1922.25	25001.24	0.2429	0.107	0.425	7.32
24.70	5.40	160.41	94.97	2233.69	1907.54	24761.04	0.2614	0.107	0.423	7.34
24.80	5.45	160.95	95.29	2249.76	1892.54	24515.99	0.2797	0.106	0.420	7.36
24.90	5.51	161.50	95.62	2265.88	1877.19	24264.50	0.2780	0.105	0.416	7.38
25.00	5.54	162.05	95.94	2282.04	1861.50	24010.96	0.2763	0.104	0.415	7.40
25.10	5.61	162.61	96.27	2298.29	1845.47	23750.78	0.2745	0.103	0.413	7.42
25.20	5.64	163.17	96.61	2314.58	1829.08	23485.36	0.2726	0.102	0.410	7.44
25.30	5.72	163.74	96.95	2330.92	1812.34	23214.61	0.2707	0.101	0.408	7.46
25.40	5.78	164.31	97.29	2347.33	1795.23	22938.43	0.2687	0.100	0.406	7.48
25.50	5.83	164.90	97.63	2363.79	1779.23	22656.86	0.2667	0.100	0.404	7.50
25.60	5.89	165.48	97.98	2380.30	1768.53	22369.93	0.2648	0.100	0.400	7.52
25.70	5.94	166.07	98.33	2396.88	1766.64	22077.44	0.2628	0.103	0.397	7.54
25.80	6.00	166.67	98.68	2413.52	1764.63	21779.32	0.2607	0.100	0.394	7.56
25.90	6.04	167.27	99.04	2430.22	1762.44	21474.76	0.2585	0.100	0.391	7.59
26.00	6.12	167.88	99.40	2446.97	1760.04	21165.09	0.2563	0.100	0.388	7.61
26.10	6.18	168.50	99.76	2463.79	1757.50	20849.52	0.2540	0.100	0.386	7.63
26.20	6.24	169.12	100.13	2480.67	1754.75	20527.29	0.2517	0.100	0.383	7.66
26.30	6.31	169.74	100.50	2497.62	1751.81	20199.64	0.2492	0.100	0.380	7.68
26.40	6.37	170.36	100.88	2514.62	1748.66	19865.82	0.2467	0.103	0.376	7.71
26.50	6.44	171.02	101.25	2531.49	1745.09	19525.75	0.2441	0.100	0.373	7.73
26.60	6.50	171.67	101.64	2548.83	1741.72	19178.71	0.2414	0.100	0.370	7.76
26.70	6.57	172.32	102.02	2566.03	1737.92	18825.93	0.2386	0.100	0.367	7.79
26.80	6.64	172.98	102.42	2583.29	1733.89	18466.66	0.2357	0.100	0.364	7.82
26.90	6.71	173.65	102.81	2600.62	1729.61	18100.20	0.2327	0.100	0.360	7.85
27.00	6.79	174.32	103.21	2618.02	1725.09	17727.80	0.2297	0.100	0.357	7.88
27.10	6.84	175.01	103.62	2635.49	1720.30	17352.17	0.2268	0.100	0.354	7.90
27.20	6.92	175.64	104.02	2653.02	1715.49	16973.39	0.2241	0.100	0.351	7.93
27.30	6.99	176.39	104.43	2670.63	1710.93	16688.69	0.2213	0.100	0.348	7.96
27.40	7.04	177.09	104.85	2688.30	1706.33	16398.97	0.2184	0.100	0.344	7.99
27.50	7.12	177.80	105.27	2706.04	1701.44	15983.70	0.2155	0.100	0.341	8.02
27.60	7.19	178.52	105.69	2723.86	1712.26	15622.30	0.2124	0.100	0.338	8.05
27.70	7.27	179.24	106.12	2741.75	1705.77	15255.93	0.2093	0.100	0.335	8.08
27.80	7.34	179.97	106.55	2759.71	1698.96	14884.01	0.2060	0.100	0.331	8.11
27.90	7.41	180.71	106.99	2777.74	1691.82	14506.08	0.2027	0.100	0.328	8.15
28.00	7.49	181.45	107.43	2795.85	1684.34	14123.16	0.1992	0.100	0.324	8.18
28.10	7.56	182.21	107.88	2814.03	1676.51	13734.78	0.1957	0.100	0.321	8.21
28.20	7.64	182.97	108.33	2832.29	1668.32	13340.54	0.1920	0.100	0.317	8.25
28.30	7.72	183.73	108.78	2850.63	1659.76	12941.46	0.1883	0.100	0.313	8.29
28.40	7.79	184.51	109.24	2869.04	1650.81	12537.14	0.1844	0.100	0.309	8.32
28.50	7.87	185.29	109.71	2887.53	1641.46	12127.22	0.1804	0.100	0.306	8.36
28.60	7.94	186.04	110.17	2906.10	1631.70	11712.76	0.1763	0.100	0.302	8.40
28.70	8.04	186.86	110.65	2924.75	1621.52	11293.43	0.1721	0.100	0.298	8.44
28.80	8.12	187.69	111.13	2943.47	1610.89	10868.94	0.1677	0.100	0.294	8.48
28.90	8.20	188.51	111.61	2962.28	1599.82	10445.40	0.1633	0.100	0.290	8.53
29.00	8.29	189.33	112.10	2981.18	1588.27	10007.54	0.1587	0.100	0.285	8.57
29.10	8.37	190.17	112.59	3000.15	1576.25	9570.24	0.1540	0.100	0.281	8.62
29.20	8.44	191.01	113.09	3019.21	1563.73	9129.55	0.1491	0.100	0.277	8.66
29.30	8.55	191.86	113.59	3038.35	1550.69	8685.02	0.1442	0.100	0.272	8.71
29.40	8.63	192.72	114.10	3057.58	1537.13	8237.67	0.1390	0.100	0.268	8.76
29.50	8.72	193.58	114.61	3076.90	1523.02	7787.56	0.1338	0.100	0.263	8.82
29.60	8.81	194.46	115.13	3096.30	1508.35	7335.79	0.1284	0.100	0.259	8.87
29.70	8.90	195.35	115.66	3115.79	1493.10	6882.87	0.1230	0.100	0.254	8.92
29.80	8.98	196.24	116.19	3135.37	1477.26	6449.73	0.1177	0.100	0.249	8.98
29.90	9.07	197.14	116.72	3155.04	1460.82	6016.18	0.1123	0.100	0.244	9.04
30.00	9.15	198.05	117.26	3174.80	1443.77	5582.54	0.1067	0.100	0.239	9.10
30.10	9.24	198.97	117.81	3194.65	1426.07	5149.30	0.1011	0.100	0.234	9.17
30.20	9.32	199.90	118.36	3214.59	1407.73	4717.55	0.0953	0.100	0.229	9.23
30.30	9.40	200.84	118.91	3234.63	1388.72	4287.75	0.0895	0.100	0.223	9.30
30.40	9.49	201.78	119.47	3254.76	1369.02	3860.99	0.0835	0.100	0.218	9.37
30.50	9.57	202.74	120.03	3274.98	1348.62	3437.96	0.0775	0.100	0.212	9.44
30.60	9.65	203.70	120.60	3295.31	1327.51	3019.86	0.0713	0.100	0.207	9.52
30.70	9.73	204.67	121.16	3315.72	1305.67	2607.60	0.0651	0.100	0.201	9.59

TABLE 7 (Cont'd)

30.80	9.81	205.64	121.75	3336.24	1283.07	2202.46	0.0588	0.100	0.195	9.67
30.90	9.84	206.62	122.34	3356.85	1259.76	2024.81	0.0603	0.100	0.189	9.76
31.00	9.83	207.61	122.92	3377.56	1235.84	1991.77	0.0581	0.100	0.183	9.85
31.10	9.83	208.59	123.50	3398.37	1211.34	1958.26	0.0567	0.100	0.177	9.93
31.20	9.83	209.57	124.08	3419.28	1186.24	1924.31	0.0558	0.100	0.171	10.03
31.30	9.83	210.54	124.66	3440.29	1160.55	1889.89	0.0554	0.100	0.165	10.12
31.40	9.83	211.54	125.25	3461.39	1134.25	1855.01	0.0552	0.100	0.159	10.22
31.50	9.83	212.52	125.83	3482.60	1107.35	1819.52	0.0552	0.100	0.152	10.32
31.60	9.83	213.51	126.41	3503.90	1079.83	1783.77	0.0549	0.100	0.146	10.42
31.70	9.83	214.49	126.99	3525.30	1051.70	1747.39	0.0546	0.100	0.140	10.53
31.80	9.82	215.47	127.57	3546.80	1022.95	1710.52	0.0543	0.100	0.133	10.64
31.90	9.82	216.45	128.15	3568.39	993.57	1673.11	0.0539	0.100	0.126	10.76
32.00	9.82	217.44	128.74	3590.09	963.56	1635.16	0.0535	0.100	0.120	10.88
32.10	9.82	218.42	129.32	3611.88	932.91	1596.69	0.0531	0.100	0.113	11.01
32.20	9.82	219.40	129.90	3633.77	901.62	1557.64	0.0527	0.100	0.106	11.14
TIME	XDOT	XDOT	XDOT	DISTANCE	M GEAR	M GEAR	DRAG	M FIRE	M FIRE	OMEGA
SEC	FT/SEC	FT/SEC	KNOTS	FT	DRAG-LB	DRAG-LB	RATIO	SINKAGE	SINKAGE	

TAKOFF VELOCITY REACHED

TABLE 8

PROBLEM A - RESULTS FOR PAVED AIRFIELD

.....  
 TAKEOFF PERFORMANCE OF AN AIRCRAFT OPERATING FROM A  
 PAVED AIRWAY WITH FRICTION COEFFICIENT OF 0.020 AND INITIAL VELOCITY OF 0. FT/SEC.  
 .....

WEIGHT = 0.1500000E 04 WING AREA= 0.2821000E 04 CL TAKEOFF = 0.6410000E 00 CD TAKEOFF = 0.4800000E-01  
 ALT (SIG)= 0.1000000E 01 SLOPE = 0.

TABLE 8 (Cont'd)

TIME SEC	ACCELERATION FT/SEC <sup>2</sup>	DISTANCE FT	VELOCITY FT/SEC	KNOTS
0.100000	0.72606	0.35693E-01	0.71689E	0.00000
0.200000	0.74711	0.14399E-00	0.14522E	0.00000
0.300000	0.76386	0.32677E-00	0.22365E	0.00000
0.400000	0.77630E	0.50593E-00	0.29801E	0.00000
0.500000	0.78344E	0.67734E-00	0.37736E	0.00000
0.600000	0.82429E	0.13613E	0.45875E	0.00000
0.700000	0.84548E	0.18417E	0.54224E	0.00000
0.800000	0.86723E	0.22265E	0.62787E	0.00000
0.900000	0.88267E	0.30881E	0.71554E	0.00000
1.000000	0.89015E	0.38579E	0.80418E	0.00000
0.110000	0.89768E	0.47067E	0.89357E	0.00000
0.120000	0.90520E	0.56453E	0.98372E	0.00000
0.130000	0.91291E	0.66744E	0.10744E	0.00000
0.140000	0.92062E	0.77948E	0.11663E	0.00000
0.150000	0.92839E	0.90073E	0.12588E	0.00000
0.160000	0.93623E	0.10313E	0.13520E	0.00000
0.170000	0.94412E	0.11712E	0.14460E	0.00000
0.180000	0.95207E	0.13205E	0.15408E	0.00000
0.190000	0.96009E	0.14793E	0.16364E	0.00000
0.200000	0.96499E	0.16478E	0.17328E	0.00000
0.210000	0.97152E	0.18259E	0.18297E	0.00000
0.220000	0.97638E	0.20138E	0.19271E	0.00000
0.230000	0.98125E	0.22114E	0.20250E	0.00000
0.240000	0.98615E	0.24188E	0.21234E	0.00000
0.250000	0.99108E	0.26360E	0.22222E	0.00000
0.260000	0.99599E	0.28632E	0.23216E	0.00000
0.270000	0.10000E	0.31004E	0.24214E	0.00000
0.280000	0.10359E	0.33475E	0.25218E	0.00000
0.290000	0.10709E	0.36047E	0.26226E	0.00000
0.300000	0.10159E	0.38721E	0.27239E	0.00000
0.310000	0.10209E	0.41495E	0.28258E	0.00000
0.320000	0.10260E	0.44372E	0.29281E	0.00000
0.330000	0.10311E	0.47352E	0.30310E	0.00000
0.340000	0.10362E	0.50344E	0.31343E	0.00000
0.350000	0.10413E	0.53211E	0.32382E	0.00000
0.360000	0.10464E	0.56911E	0.33426E	0.00000
0.370000	0.10499E	0.60306E	0.34474E	0.00000
0.380000	0.10523E	0.63806E	0.35525E	0.00000
0.390000	0.10547E	0.67411E	0.36579E	0.00000
0.400000	0.10572E	0.71122E	0.37635E	0.00000
0.410000	0.10597E	0.74938E	0.38693E	0.00000
0.420000	0.10622E	0.78861E	0.39754E	0.00000
0.430000	0.10647E	0.82889E	0.40818E	0.00000
0.440000	0.10672E	0.87024E	0.41884E	0.00000
0.450000	0.10697E	0.91246E	0.42952E	0.00000
0.460000	0.10721E	0.95615E	0.44023E	0.00000
0.470000	0.10746E	0.10007E	0.45096E	0.00000
0.480000	0.10771E	0.10463E	0.46172E	0.00000
0.490000	0.10796E	0.10931E	0.47251E	0.00000
0.500000	0.10821E	0.11408E	0.48331E	0.00000
0.510000	0.10846E	0.11897E	0.49415E	0.00000
0.520000	0.10870E	0.12397E	0.50500E	0.00000
0.530000	0.10895E	0.12907E	0.51588E	0.00000
0.540000	0.10920E	0.13428E	0.52677E	0.00000
0.550000	0.10945E	0.13961E	0.53767E	0.00000
0.560000	0.10970E	0.14504E	0.54858E	0.00000
0.570000	0.10995E	0.15058E	0.55950E	0.00000
0.580000	0.11020E	0.15623E	0.57044E	0.00000
0.590000	0.11045E	0.16199E	0.58138E	0.00000
0.600000	0.11070E	0.16786E	0.59232E	0.00000

TABLE 8 (Cont'd)

0.6000E	01	0.10959E	02	0.16786E	03	0.59233E	02	0.35070E	02
0.61000E	01	0.10970E	02	0.17383E	03	0.60330E	02	0.35719E	02
0.62000E	01	0.10980E	02	0.17992E	03	0.61427E	02	0.36369E	02
0.63000E	01	0.10991E	02	0.18612E	03	0.62526E	02	0.37020E	02
0.64000E	01	0.11001E	02	0.19243E	03	0.63626E	02	0.37671E	02
0.65000E	01	0.11012E	02	0.19884E	03	0.64726E	02	0.38322E	02
0.66000E	01	0.11022E	02	0.20537E	03	0.65828E	02	0.38974E	02
0.67000E	01	0.11032E	02	0.21201E	03	0.66931E	02	0.39627E	02
0.68000E	01	0.11039E	02	0.21876E	03	0.68034E	02	0.40281E	02
0.69000E	01	0.11040E	02	0.22562E	03	0.69138E	02	0.40934E	02
0.70000E	01	0.11040E	02	0.23259E	03	0.70242E	02	0.41588E	02
0.71000E	01	0.11041E	02	0.23967E	03	0.71346E	02	0.42242E	02
0.72000E	01	0.11042E	02	0.24686E	03	0.72450E	02	0.42895E	02
0.73000E	01	0.11042E	02	0.25416E	03	0.73555E	02	0.43549E	02
0.74000E	01	0.11043E	02	0.26157E	03	0.74659E	02	0.44203E	02
0.75000E	01	0.11043E	02	0.26909E	03	0.75763E	02	0.44857E	02
0.76000E	01	0.11044E	02	0.27672E	03	0.76868E	02	0.45511E	02
0.77000E	01	0.11044E	02	0.28446E	03	0.77972E	02	0.46165E	02
0.78000E	01	0.11044E	02	0.29231E	03	0.79076E	02	0.46813E	02
0.79000E	01	0.11045E	02	0.30028E	03	0.80181E	02	0.47472E	02
0.80000E	01	0.11045E	02	0.30835E	03	0.81285E	02	0.48126E	02
0.81000E	01	0.11045E	02	0.31653E	03	0.82390E	02	0.48780E	02
0.82000E	01	0.11045E	02	0.32483E	03	0.83494E	02	0.49434E	02
0.83000E	01	0.11045E	02	0.33323E	03	0.84599E	02	0.50088E	02
0.84000E	01	0.11045E	02	0.34175E	03	0.85703E	02	0.50742E	02
0.85000E	01	0.11045E	02	0.35037E	03	0.86808E	02	0.51396E	02
0.86000E	01	0.11045E	02	0.35911E	03	0.87912E	02	0.52050E	02
0.87000E	01	0.11044E	02	0.36796E	03	0.89017E	02	0.52704E	02
0.88000E	01	0.11044E	02	0.37691E	03	0.90121E	02	0.53358E	02
0.89000E	01	0.11044E	02	0.38598E	03	0.91225E	02	0.54012E	02
0.90000E	01	0.11043E	02	0.39516E	03	0.92330E	02	0.54665E	02
0.91000E	01	0.11043E	02	0.40445E	03	0.93434E	02	0.55319E	02
0.92000E	01	0.11042E	02	0.41384E	03	0.94538E	02	0.55973E	02
0.93000E	01	0.11041E	02	0.42335E	03	0.95643E	02	0.56627E	02
0.94000E	01	0.11041E	02	0.43297E	03	0.96747E	02	0.57280E	02
0.95000E	01	0.11040E	02	0.44270E	03	0.97851E	02	0.57934E	02
0.96000E	01	0.11039E	02	0.45254E	03	0.98955E	02	0.58588E	02
0.97000E	01	0.11038E	02	0.46249E	03	1.00060E	02	0.59241E	02
0.98000E	01	0.11037E	02	0.47255E	03	1.01166E	02	0.59895E	02
0.99000E	01	0.11036E	02	0.48273E	03	1.02270E	02	0.60548E	02
1.00000E	01	0.11035E	02	0.49301E	03	1.03375E	02	0.61202E	02
0.10100E	02	0.11034E	02	0.50340E	03	1.04479E	02	0.61855E	02
0.10200E	02	0.11033E	02	0.51390E	03	1.05583E	02	0.62508E	02
0.10300E	02	0.11032E	02	0.52451E	03	1.06688E	02	0.63161E	02
0.10400E	02	0.11030E	02	0.53524E	03	1.07782E	02	0.63815E	02
0.10500E	02	0.11029E	02	0.54607E	03	1.08886E	02	0.64468E	02
0.10600E	02	0.11028E	02	0.55702E	03	1.09990E	02	0.65120E	02
0.10700E	02	0.11026E	02	0.56807E	03	1.11094E	02	0.65773E	02
0.10800E	02	0.11025E	02	0.57923E	03	1.12198E	02	0.66426E	02
0.10900E	02	0.11023E	02	0.59051E	03	1.13302E	02	0.67079E	02
0.11000E	02	0.11021E	02	0.60189E	03	1.14406E	02	0.67731E	02
0.11100E	02	0.11020E	02	0.61339E	03	1.15509E	02	0.68384E	02
0.11200E	02	0.11018E	02	0.62499E	03	1.16603E	02	0.69036E	02
0.11300E	02	0.11016E	02	0.63671E	03	1.17707E	02	0.69689E	02
0.11400E	02	0.11012E	02	0.64853E	03	1.18811E	02	0.70341E	02
0.11500E	02	0.11005E	02	0.66047E	03	1.19915E	02	0.70992E	02
0.11600E	02	0.10998E	02	0.67251E	03	1.21019E	02	0.71644E	02
0.11700E	02	0.10991E	02	0.68467E	03	1.22123E	02	0.72295E	02
0.11800E	02	0.10985E	02	0.69694E	03	1.23227E	02	0.72945E	02
0.11900E	02	0.10978E	02	0.70931E	03	1.24331E	02	0.73595E	02
0.12000E	02	0.10971E	02	0.72180E	03	1.25435E	02	0.74245E	02
0.12100E	02	0.10964E	02	0.73439E	03	1.26539E	02	0.74895E	02

TABLE 8 (Cont'd)

0.12200E 02	0.10957E 02	0.74710E 03	0.12759E 03	0.12759E 03	0.75543E 02
0.12300E 02	0.10950E 02	0.75991E 03	0.12869E 03	0.12869E 03	0.76192E 02
0.12400E 02	0.10943E 02	0.77283E 03	0.12978E 03	0.12978E 03	0.76840E 02
0.12500E 02	0.10935E 02	0.78587E 03	0.13088E 03	0.13088E 03	0.77488E 02
0.12600E 02	0.10928E 02	0.79901E 03	0.13197E 03	0.13197E 03	0.78135E 02
0.12700E 02	0.10921E 02	0.81226E 03	0.13306E 03	0.13306E 03	0.78782E 02
0.12800E 02	0.10913E 02	0.82562E 03	0.13415E 03	0.13415E 03	0.79428E 02
0.12900E 02	0.10906E 02	0.83909E 03	0.13525E 03	0.13525E 03	0.80074E 02
0.13000E 02	0.10899E 02	0.85267E 03	0.13634E 03	0.13634E 03	0.80720E 02
0.13100E 02	0.10891E 02	0.86636E 03	0.13742E 03	0.13742E 03	0.81365E 02
0.13200E 02	0.10883E 02	0.88015E 03	0.13851E 03	0.13851E 03	0.82009E 02
0.13300E 02	0.10876E 02	0.89406E 03	0.13960E 03	0.13960E 03	0.82653E 02
0.13400E 02	0.10868E 02	0.90807E 03	0.14069E 03	0.14069E 03	0.83297E 02
0.13500E 02	0.10860E 02	0.92220E 03	0.14178E 03	0.14178E 03	0.83940E 02
0.13600E 02	0.10853E 02	0.93643E 03	0.14286E 03	0.14286E 03	0.84583E 02
0.13700E 02	0.10845E 02	0.95077E 03	0.14395E 03	0.14395E 03	0.85225E 02
0.13800E 02	0.10837E 02	0.96522E 03	0.14503E 03	0.14503E 03	0.85867E 02
0.13900E 02	0.10829E 02	0.97978E 03	0.14611E 03	0.14611E 03	0.86509E 02
0.14000E 02	0.10821E 02	0.99444E 03	0.14720E 03	0.14720E 03	0.87149E 02
0.14100E 02	0.10813E 02	0.10092E 04	0.14828E 03	0.14828E 03	0.87790E 02
0.14200E 02	0.10805E 02	0.10241E 04	0.14936E 03	0.14936E 03	0.88430E 02
0.14300E 02	0.10796E 02	0.10391E 04	0.15044E 03	0.15044E 03	0.89069E 02
0.14400E 02	0.10788E 02	0.10542E 04	0.15152E 03	0.15152E 03	0.89708E 02
0.14500E 02	0.10780E 02	0.10694E 04	0.15260E 03	0.15260E 03	0.90347E 02
0.14600E 02	0.10772E 02	0.10847E 04	0.15367E 03	0.15367E 03	0.90985E 02
0.14700E 02	0.10763E 02	0.11001E 04	0.15475E 03	0.15475E 03	0.91622E 02
0.14800E 02	0.10755E 02	0.11155E 04	0.15583E 03	0.15583E 03	0.92259E 02
0.14900E 02	0.10746E 02	0.11313E 04	0.15690E 03	0.15690E 03	0.92896E 02
0.15000E 02	0.10738E 02	0.11470E 04	0.15798E 03	0.15798E 03	0.93532E 02
0.15100E 02	0.10729E 02	0.11629E 04	0.15905E 03	0.15905E 03	0.94167E 02
0.15200E 02	0.10720E 02	0.11788E 04	0.16012E 03	0.16012E 03	0.94802E 02
0.15300E 02	0.10712E 02	0.11949E 04	0.16119E 03	0.16119E 03	0.95437E 02
0.15400E 02	0.10703E 02	0.12111E 04	0.16226E 03	0.16226E 03	0.96071E 02
0.15500E 02	0.10694E 02	0.12274E 04	0.16333E 03	0.16333E 03	0.96704E 02
0.15600E 02	0.10685E 02	0.12437E 04	0.16440E 03	0.16440E 03	0.97337E 02
0.15700E 02	0.10675E 02	0.12602E 04	0.16547E 03	0.16547E 03	0.97969E 02
0.15800E 02	0.10667E 02	0.12768E 04	0.16654E 03	0.16654E 03	0.98601E 02
0.15900E 02	0.10658E 02	0.12935E 04	0.16760E 03	0.16760E 03	0.99232E 02
0.16000E 02	0.10649E 02	0.13104E 04	0.16867E 03	0.16867E 03	0.99863E 02
0.16100E 02	0.10640E 02	0.13273E 04	0.16973E 03	0.16973E 03	0.10049E 03
0.16200E 02	0.10631E 02	0.13443E 04	0.17080E 03	0.17080E 03	0.10112E 03
0.16300E 02	0.10622E 02	0.13614E 04	0.17186E 03	0.17186E 03	0.10175E 03
0.16400E 02	0.10613E 02	0.13787E 04	0.17292E 03	0.17292E 03	0.10238E 03
0.16500E 02	0.10603E 02	0.13960E 04	0.17398E 03	0.17398E 03	0.10301E 03
0.16600E 02	0.10594E 02	0.14135E 04	0.17504E 03	0.17504E 03	0.10364E 03
0.16700E 02	0.10585E 02	0.14310E 04	0.17610E 03	0.17610E 03	0.10426E 03
0.16800E 02	0.10575E 02	0.14487E 04	0.17716E 03	0.17716E 03	0.10489E 03
0.16900E 02	0.10566E 02	0.14665E 04	0.17822E 03	0.17822E 03	0.10552E 03
0.17000E 02	0.10556E 02	0.14845E 04	0.17927E 03	0.17927E 03	0.10614E 03
0.17100E 02	0.10547E 02	0.15023E 04	0.18033E 03	0.18033E 03	0.10677E 03
0.17200E 02	0.10537E 02	0.15204E 04	0.18138E 03	0.18138E 03	0.10739E 03
0.17300E 02	0.10527E 02	0.15386E 04	0.18243E 03	0.18243E 03	0.10801E 03
0.17400E 02	0.10518E 02	0.15569E 04	0.18349E 03	0.18349E 03	0.10864E 03
0.17500E 02	0.10508E 02	0.15753E 04	0.18454E 03	0.18454E 03	0.10926E 03
0.17600E 02	0.10498E 02	0.15938E 04	0.18559E 03	0.18559E 03	0.10988E 03
0.17700E 02	0.10488E 02	0.16124E 04	0.18664E 03	0.18664E 03	0.11050E 03
0.17800E 02	0.10478E 02	0.16311E 04	0.18769E 03	0.18769E 03	0.11112E 03
0.17900E 02	0.10468E 02	0.16499E 04	0.18873E 03	0.18873E 03	0.11174E 03
0.18000E 02	0.10458E 02	0.16689E 04	0.18978E 03	0.18978E 03	0.11236E 03
0.18100E 02	0.10448E 02	0.16879E 04	0.19083E 03	0.19083E 03	0.11298E 03
0.18200E 02	0.10438E 02	0.17070E 04	0.19187E 03	0.19187E 03	0.11360E 03
0.18300E 02	0.10428E 02	0.17263E 04	0.19291E 03	0.19291E 03	0.11422E 03

TABLE 8 (Cont'd)

TIME	ACCELERATION	DISTANCE	VELOCITY
SEC	FT/SEC**2	FT	FT/SEC KNOTS
0.18400E	02	0.10418E	02 0.17456E 04 0.19396E 03 0.11483E 03
0.18500E	02	0.10408E	02 0.17651E 04 0.19500E 03 0.11545E 03
0.18600E	02	0.10397E	02 0.17846E 04 0.19604E 03 0.11607E 03
0.18700E	02	0.10387E	02 0.18043E 04 0.19708E 03 0.11668E 03
0.18800E	02	0.10377E	02 0.18240E 04 0.19811E 03 0.11730E 03
0.18900E	02	0.10366E	02 0.18439E 04 0.19915E 03 0.11791E 03
0.19000E	02	0.10356E	02 0.18639E 04 0.20019E 03 0.11852E 03
0.19100E	02	0.10345E	02 0.18839E 04 0.20122E 03 0.11914E 03
0.19200E	02	0.10335E	02 0.19041E 04 0.20226E 03 0.11975E 03
0.19300E	02	0.10324E	02 0.19244E 04 0.20329E 03 0.12036E 03
0.19400E	02	0.10313E	02 0.19448E 04 0.20432E 03 0.12097E 03
0.19500E	02	0.10303E	02 0.19653E 04 0.20535E 03 0.12158E 03
0.19600E	02	0.10292E	02 0.19858E 04 0.20638E 03 0.12219E 03
0.19700E	02	0.10281E	02 0.20065E 04 0.20741E 03 0.12280E 03
0.19800E	02	0.10271E	02 0.20273E 04 0.20844E 03 0.12341E 03
0.19900E	02	0.10260E	02 0.20482E 04 0.20946E 03 0.12402E 03
0.20000E	02	0.10249E	02 0.20692E 04 0.21049E 03 0.12462E 03
0.20100E	02	0.10238E	02 0.20903E 04 0.21151E 03 0.12523E 03
0.20200E	02	0.10227E	02 0.21115E 04 0.21254E 03 0.12584E 03
0.20300E	02	0.10216E	02 0.21328E 04 0.21356E 03 0.12644E 03
0.20400E	02	0.10205E	02 0.21542E 04 0.21458E 03 0.12705E 03
0.20500E	02	0.10194E	02 0.21757E 04 0.21560E 03 0.12765E 03
0.20600E	02	0.10183E	02 0.21973E 04 0.21662E 03 0.12825E 03
0.20700E	02	0.10172E	02 0.22191E 04 0.21764E 03 0.12886E 03
0.20800E	02	0.10160E	02 0.22409E 04 0.21865E 03 0.12946E 03

TABLE 9

## PROBLEM B - RESULTS

\*\*\*\*\*  
 SOIL DRAG FOR COMPLETE SET OF TIRES ROLLING ON CLAY SOIL  
 WITH A CONE INDEX OF 90. AND CONSTANT TAXI VELOCITY  
 \*\*\*\*\*

WEIGHT = 0.1500000E 06 VELOCITY = 0.5000000E 01 W NOSE TIRE= 0.1065000E 02 D NOSE TIRE= 0.3070000E 02  
 M TANDEM = 0 M TANDEM = 4 W MAIN TIRE= 0.1500000E 02 D MAIN TIRE= 0.4500000E 02  
 TOT DRAG = 0.1264963E 05 FD/FV = 0.8441703E-01 N SINKAGE = 0.2718348E-00 M SINKAGE = 0.1017493E 01  
 NOSE DRAG = 0.3385706E 03 MAIN DRAG = 0.1231106E 05 MU STAR N = 0.4056894E-01 MU STAR M = 0.8551198E-01

\*\*\*\*\*  
 SOIL DRAG FOR COMPLETE SET OF TIRES ROLLING ON CLAY SOIL  
 WITH A CONE INDEX OF 90. AND CONSTANT TAXI VELOCITY  
 \*\*\*\*\*

WEIGHT = 0.1500000E 06 VELOCITY = 0.2000000E 02 W NOSE TIRE= 0.1065000E 02 D NOSE TIRE= 0.3070000E 02  
 M TANDEM = 0 M TANDEM = 4 W MAIN TIRE= 0.1500000E 02 D MAIN TIRE= 0.4500000E 02  
 TOT DRAG = 0.1235308E 05 FD/FV = 0.8372065E-01 N SINKAGE = 0.2223014E-00 M SINKAGE = 0.7869715E 00  
 NOSE DRAG = 0.4521385E 03 MAIN DRAG = 0.1190094E 05 MU STAR N = 0.3589269E-01 MU STAR M = 0.6236460E-01

\*\*\*\*\*  
 SOIL DRAG FOR COMPLETE SET OF TIRES ROLLING ON CLAY SOIL  
 WITH A CONE INDEX OF 90. AND CONSTANT TAXI VELOCITY  
 \*\*\*\*\*

WEIGHT = 0.1500000E 06 VELOCITY = 0.3500000E 02 W NOSE TIRE= 0.1065000E 02 D NOSE TIRE= 0.3070000E 02  
 M TANDEM = 0 M TANDEM = 4 W MAIN TIRE= 0.1500000E 02 D MAIN TIRE= 0.4500000E 02  
 TOT DRAG = 0.1595316E 05 FD/FV = 0.1119516E-00 N SINKAGE = 0.2128786E-00 M SINKAGE = 0.7295045E 00  
 NOSE DRAG = 0.7416288E 03 MAIN DRAG = 0.1521153E 05 MU STAR N = 0.3423404E-01 MU STAR M = 0.6469822E-01

TABLE 9 (Cont'd)

SOIL DRAG FOR COMPLETE SET OF TIRES ROLLING ON CLAY SOIL WITH A CONE INDEX OF 90. AND CONSTANT TAXI VELOCITY									
WEIGHT	=	0.1500000E 06	VELOCITY	=	0.5000000E 02	W NOSE TIRE=	0.1065000E 02	D NOSE TIRE=	0.3070000E 02
N TANDEM	=	0	M TANDEM	=	4	W MAIN TIRE=	0.1500000E 02	D MAIN TIRE=	0.4500000E 02
TOT DRAG	=	0.2109074E 05	FD/FV	=	0.1565815E-00	N SINKAGE	=	0.1950466E-00	M SINKAGE = 0.6738495E 00
NOSE DRAG	=	0.1130942E 04	MAIN DRAG	=	0.1995980E 05	MU STAR N	=	0.3231501E-01	MU STAR M = 0.6065696E-01
SOIL DRAG FOR COMPLETE SET OF TIRES ROLLING ON CLAY SOIL WITH A CONE INDEX OF 90. AND CONSTANT TAXI VELOCITY									
WEIGHT	=	0.1500000E 06	VELOCITY	=	0.6500000E 02	W NOSE TIRE=	0.1065000E 02	D NOSE TIRE=	0.3070000E 02
N TANDEM	=	0	M TANDEM	=	4	W MAIN TIRE=	0.1500000E 02	D MAIN TIRE=	0.4500000E 02
TOT DRAG	=	0.2670602E 05	FD/FV	=	0.2151377E-00	N SINKAGE	=	0.1721711E-00	M SINKAGE = 0.6069466E 00
NOSE DRAG	=	0.1538600E 04	MAIN DRAG	=	0.2516742E 05	MU STAR N	=	0.3000000E-01	MU STAR M = 0.5579082E-01
SOIL DRAG FOR COMPLETE SET OF TIRES ROLLING ON CLAY SOIL WITH A CONE INDEX OF 90. AND CONSTANT TAXI VELOCITY									
WEIGHT	=	0.1500000E 06	VELOCITY	=	0.8000000E 02	W NOSE TIRE=	0.1065000E 02	D NOSE TIRE=	0.3070000E 02
N TANDEM	=	0	M TANDEM	=	4	W MAIN TIRE=	0.1500000E 02	D MAIN TIRE=	0.4500000E 02
TOT DRAG	=	0.3144119E 05	FD/FV	=	0.2837161E-00	N SINKAGE	=	0.1430729E-00	M SINKAGE = 0.5243401E 00
NOSE DRAG	=	0.1863645E 04	MAIN DRAG	=	0.2957754E 05	MU STAR N	=	0.3000000E-01	MU STAR M = 0.4977016E-01

TABLE 9 (Cont'd)

.....  
 SOIL DRAG FOR COMPLETE SET OF TIRES ROLLING ON CLAY SOIL  
 WITH A CONE INDEX OF 90. AND CONSTANT TAXI VELOCITY  
 .....

WEIGHT = 0.1500000E 06 VELOCITY = 0.9500000E 02 W NOSE TIRE= 0.1065000E 02 D NOSE TIRE= 0.3070000E 02  
 N TANDEM = 0 M TANDEM = 4 W MAIN TIRE= 0.1500000E 02 D MAIN TIRE= 0.4500000E 02  
 TOT DRAG = 0.2664479E 05 FD/FV = 0.2812146E-00 N SINKAGE = 0.1065326E-00 M SINKAGE = .4225264E-00  
 NOSE DRAG = 0.1906184E 04 MAIN DRAG = 0.2473861E 05 MU STAR N = 0.3000000E-01 MU STAR M = 0.4233084E-01

.....  
 SOIL DRAG FOR COMPLETE SET OF TIRES ROLLING ON CLAY SOIL  
 WITH A CONE INDEX OF 90. AND CONSTANT TAXI VELOCITY  
 .....

WEIGHT = 0.1500000E 06 VELOCITY = 0.1100000E 03 W NOSE TIRE= 0.1065000E 02 D NOSE TIRE= 0.3070000E 02  
 N TANDEM = 0 M TANDEM = 4 W MAIN TIRE= 0.1500000E 02 D MAIN TIRE= 0.4500000E 02  
 TOT DRAG = 0.1370589E 05 FD/FV = 0.1805217E-00 N SINKAGE = 0.1000000E-00 M SINKAGE = 0.3031742E-00  
 NOSE DRAG = 0.1839328E 04 MAIN DRAG = 0.1186657E 05 MU STAR N = 0.8008662E-01 MU STAR M = 0.3358349E-01

TABLE 10

PROBLEM C - RESULTS

SOIL DRAG FOR A SINGLE SET OF TIRES ROLLING ON CLAY SOIL  
WITH A CONE INDEX OF 90. AND CONSTANT TAXI VELOCITY

WEIGHT = 0.8872140E 04 VELOCITY = 0.5000000E 01 TIRE WIDTH = 0.1500000E 02 TIRE DIA = 0.4500000E 02  
SINKAGE = 0.1018694E 01 DRAG = 0.1541989E 04 SOIL TYPE = 1 TANDEM = 1  
FD/FV = 0.8690062E-01 MU STAR1 = 0.8559841E-01 MU STAR2 = 0.8559841E-01

SOIL DRAG FOR A SINGLE SET OF TIRES ROLLING ON CLAY SOIL  
WITH A CONE INDEX OF 90. AND CONSTANT TAXI VELOCITY

WEIGHT = 0.8872140E 04 VELOCITY = 0.1500000E 02 TIRE WIDTH = 0.1500000E 02 TIRE DIA = 0.4500000E 02  
SINKAGE = 0.8244918E 00 DRAG = 0.1438475E 04 SOIL TYPE = 1 TANDEM = 1  
FD/FV = 0.8106495E-01 MU STAR1 = 0.7158131E-01 MU STAR2 = 0.7158131E-01

SOIL DRAG FOR A SINGLE SET OF TIRES ROLLING ON CLAY SOIL  
WITH A CONE INDEX OF 90. AND CONSTANT TAXI VELOCITY

WEIGHT = 0.8872140E 04 VELOCITY = 0.2500000E 02 TIRE WIDTH = 0.1500000E 02 TIRE DIA = 0.4500000E 02  
SINKAGE = 0.7880775E 00 DRAG = 0.1670269E 04 SOIL TYPE = 1 TANDEM = 1  
FD/FV = 0.9413002E-01 MU STAR1 = 0.6894472E-01 MU STAR2 = 0.6894472E-01

SOIL DRAG FOR A SINGLE SET OF TIRES ROLLING ON CLAY SOIL  
WITH A CONE INDEX OF 90. AND CONSTANT TAXI VELOCITY

WEIGHT = 0.8872140E 04 VELOCITY = 0.3500000E 02 TIRE WIDTH = 0.1500000E 02 TIRE DIA = 0.4500000E 02  
SINKAGE = 0.7727318E 00 DRAG = 0.2062503E 04 SOIL TYPE = 1 TANDEM = 1  
FD/FV = 0.1162348E-00 MU STAR1 = 0.6783292E-01 MU STAR2 = 0.6783292E-01

TABLE 10 (Cont'd)

```

.....
SOIL DRAG FOR A SINGLE SET OF TIRES ROLLING ON CLAY SOIL
WITH A CONE INDEX OF 90. AND CONSTANT TAXI VELOCITY
.....

WEIGHT = 0.8672140E 04 VELOCITY = 0.4500000E 02 TIRE WIDTH = 0.1500000E 02 TIRE DIA = 0.4500000E 02
SINKAGE = 0.7642498E 00 DRAG = 0.2597053E 04 SOIL TYPE = 1 TANDEM = 1
FO/FV = 0.1463600E-00 MU STAR1 = 0.6722167E-01 MU STAR2 = 0.6722167E-01

.....
SOIL DRAG FOR A SINGLE SET OF TIRES ROLLING ON CLAY SOIL
WITH A CONE INDEX OF 90. AND CONSTANT TAXI VELOCITY
.....

WEIGHT = 0.8872140E 04 VELOCITY = 0.5500000E 02 TIRE WIDTH = 0.1500000E 02 TIRE DIA = 0.4500000E 02
SINKAGE = 0.7589144E 00 DRAG = 0.3268803E 04 SOIL TYPE = 1 TANDEM = 1
FO/FV = 0.1842173E-00 MU STAR1 = 0.6683127E-01 MU STAR2 = 0.6683127E-01

.....
SOIL DRAG FOR A SINGLE SET OF TIRES ROLLING ON CLAY SOIL
WITH A CONE INDEX OF 90. AND CONSTANT TAXI VELOCITY
.....

WEIGHT = 0.8872140E 04 VELOCITY = 0.6500000E 02 TIRE WIDTH = 0.1500000E 02 TIRE DIA = 0.4500000E 02
SINKAGE = 0.7552242E 00 DRAG = 0.4076195E 04 SOIL TYPE = 1 TANDEM = 1
FO/FV = 0.2297188E-00 MU STAR1 = 0.6656371E-01 MU STAR2 = 0.6656371E-01

.....
SOIL DRAG FOR A SINGLE SET OF TIRES ROLLING ON CLAY SOIL
WITH A CONE INDEX OF 90. AND CONSTANT TAXI VELOCITY
.....

WEIGHT = 0.8872140E 04 VELOCITY = 0.7500000E 02 TIRE WIDTH = 0.1500000E 02 TIRE DIA = 0.4500000E 02
SINKAGE = 0.7525210E 00 DRAG = 0.5018240E 04 SOIL TYPE = 1 TANDEM = 1
FO/FV = 0.2828089E-00 MU STAR1 = 0.6636777E-01 MU STAR2 = 0.6636777E-01

```

TABLE 10 (Cont'd)

..... SOIL DRAG FOR A SINGLE SET OF TIRES ROLLING ON CLAY SOIL WITH A CONE INDEX OF 90. AND CONSTANT TAXI VELOCITY .....						
WEIGHT	= 0.8872140E 04	VELOCITY	= 0.8500000E 02	TIRE WIDTH	= 0.1500000E 02	TIRE DIA = 0.4500000E 02
SINKAGE	= 0.7504576E 00	DRAG	= 0.6094487E 04	SOIL TYPE	= 1	TANDEM = 1
FD/FV	= 0.3434621E-00	MU STAR1	= 0.6621808E-01	MU STAR2	= 0.6621808E-01	
..... SOIL DRAG FOR A SINGLE SET OF TIRES ROLLING ON CLAY SOIL WITH A CONE INDEX OF 90. AND CONSTANT TAXI VELOCITY .....						
WEIGHT	= 0.8872140E 04	VELOCITY	= 0.9500000E 02	TIRE WIDTH	= 0.1500000E 02	TIRE DIA = 0.4500000E 02
SINKAGE	= 0.7488141E 00	DRAG	= 0.6410694E 04	SOIL TYPE	= 1	TANDEM = 1
FD/FV	= 0.3941282E-00	MU STAR1	= 0.6609890E-01	MU STAR2	= 0.6609890E-01	
..... SOIL DRAG FOR A SINGLE SET OF TIRES ROLLING ON CLAY SOIL WITH A CONE INDEX OF 90. AND CONSTANT TAXI VELOCITY .....						
WEIGHT	= 0.8872140E 04	VELOCITY	= 0.1050000E 03	TIRE WIDTH	= 0.1500000E 02	TIRE DIA = 0.4500000E 02
SINKAGE	= 0.7474983E 00	DRAG	= 0.5897695E 04	SOIL TYPE	= 1	TANDEM = 1
FD/FV	= 0.3323716E-00	MU STAR1	= 0.6600348E-01	MU STAR2	= 0.6600348E-01	
..... SOIL DRAG FOR A SINGLE SET OF TIRES ROLLING ON CLAY SOIL WITH A CONE INDEX OF 90. AND CONSTANT TAXI VELOCITY .....						
WEIGHT	= 0.8872140E 04	VELOCITY	= 0.1150000E 03	TIRE WIDTH	= 0.1500000E 02	TIRE DIA = 0.4500000E 02
SINKAGE	= 0.7464120E 00	DRAG	= 0.4841908E 04	SOIL TYPE	= 1	TANDEM = 1
FD/FV	= 0.2728715E-00	MU STAR1	= 0.6592469E-01	MU STAR2	= 0.6592469E-01	

## APPENDIX D

### DATA USED TO DESCRIBE THE BOEING 367-80 AIRCRAFT

1. Discussion - This appendix gives the detail data used in the correlation made in Section IV. Most of the information was taken from Reference 2. A number of items were not specified, however, and other sources were used to obtain the information. The takeoff velocity required for lift-off at a particular gross weight was obtained from Reference 3, and is presented as Table 11. Another problem was center of gravity variation with gross weight. It was convenient in the computer program to use the center of gravity as number of feet forward of the main landing gear strut. A curve of Reference 2 was converted to the convenient form of Figure 112. The remaining information is presented in tabulated form below:

#### 367-80 Aircraft Data

Item	Symbol Used in Computer Program	Value
Number of Main Landing Gear Tires	WMC	8 per strut
Width of Main Gear Tire	BM	15 in.
Diameter of Main Gear Tire	DM	45 in.
Main Gear Tire Section Height	HTM	10.75 in.
Number of Nose Landing Gear Tires	WNG	4
Width of Nose Gear Tires	BN	10.65 in.
Diameter of Nose Gear Tires	DN	30.7 in
Nose Tire Section Height	HTN	6.6 in
Number of Main Gear Tandem Wheel Sets	NTANDM	4 per strut
Number of Nose Gear Tandem Wheel Sets	NTANDN	0
Distance Between Nose and Main Gear Strut	DWB	44 Feet
Distance Between Main Gear Strut and c.g.	DCG	See Fig. 112
Gross Weight of Vehicle	W	120-200 KIP
Wing Area	AW	2821 Sq. Ft.

367-80 Aircraft Data (Cont'd)

Item Item	Symbol Used in Computer Program	Value
Lift Coefficient During Takeoff 20° Flap	CL	0.641
Drag Coefficient During Takeoff 20° Flap	CD	0.048
Atmospheric Density Ratio	SIG	1
Slope of Runway	SLOPE	0 rad
Soil Density	RHOS	$2.6 \frac{\text{lb sec}^2}{\text{ft}^4}$
Clay Soil Strength	CI	80 to 200
Sandy Soil Strength	G	20 to 150
Paved Surface Friction Coefficient	RRC	0.02
Number of Engines	NENGS	4
Thrust of Engines	XVEL, YTH	See Figure 113
Velocity Required for Takeoff	VTO	See Table 11
Soil Type	NTYP	Clay and Sand
Load Deflection Curve for Main Gear Tire (46 x 16 Type VII 26 PR 30 PSI Inflation)	XFVM, YDFM	See Figure 114
Load Deflection Curve for Nose Gear Tire (32 x 11.50-15 12 PR Type VIII at 36 PSI Inflation)	XFVN, YDFN	See Figure 115

TABLE 11  
KC-135 TAKEOFF SPEED

Gross Weight 1000 Pounds	SPEED-Knots	
	20° Flap	30° Flap
300	184	177
290	181	174
280	177	171
270	174	168
260	171	165
250	168	162
240	164	159
230	161	155
220	157	152
210	154	148
200	150	145
190	146	141
180	143	137
170	138	134
160	134	130
150	130	125
140	126	121
130	121	117
120	116	112
110	111	107
100	106	103
211		

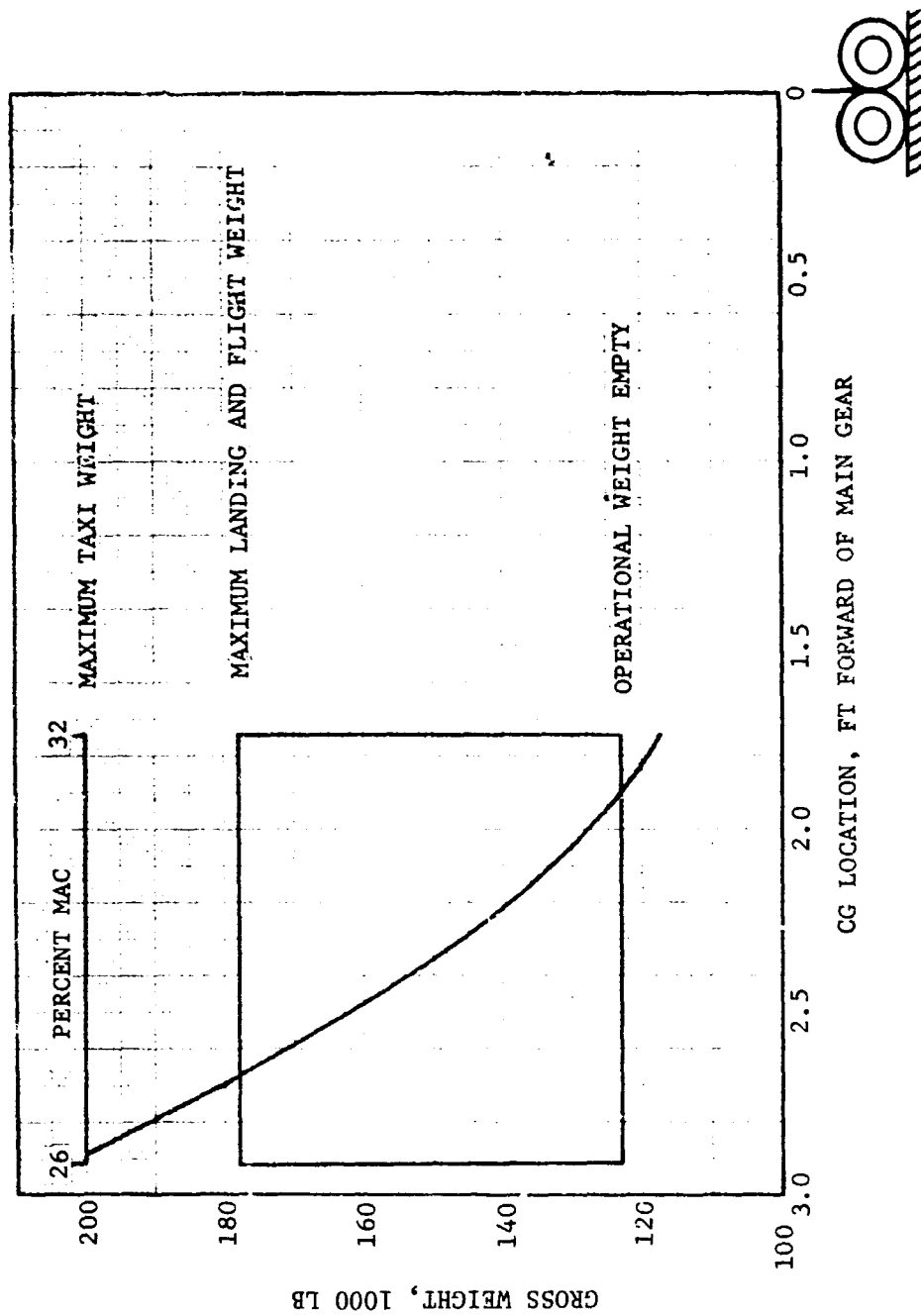


Figure 112 CG Location as a Function of Gross Weight for Boeing 367-80 H1-Flotation Configuration

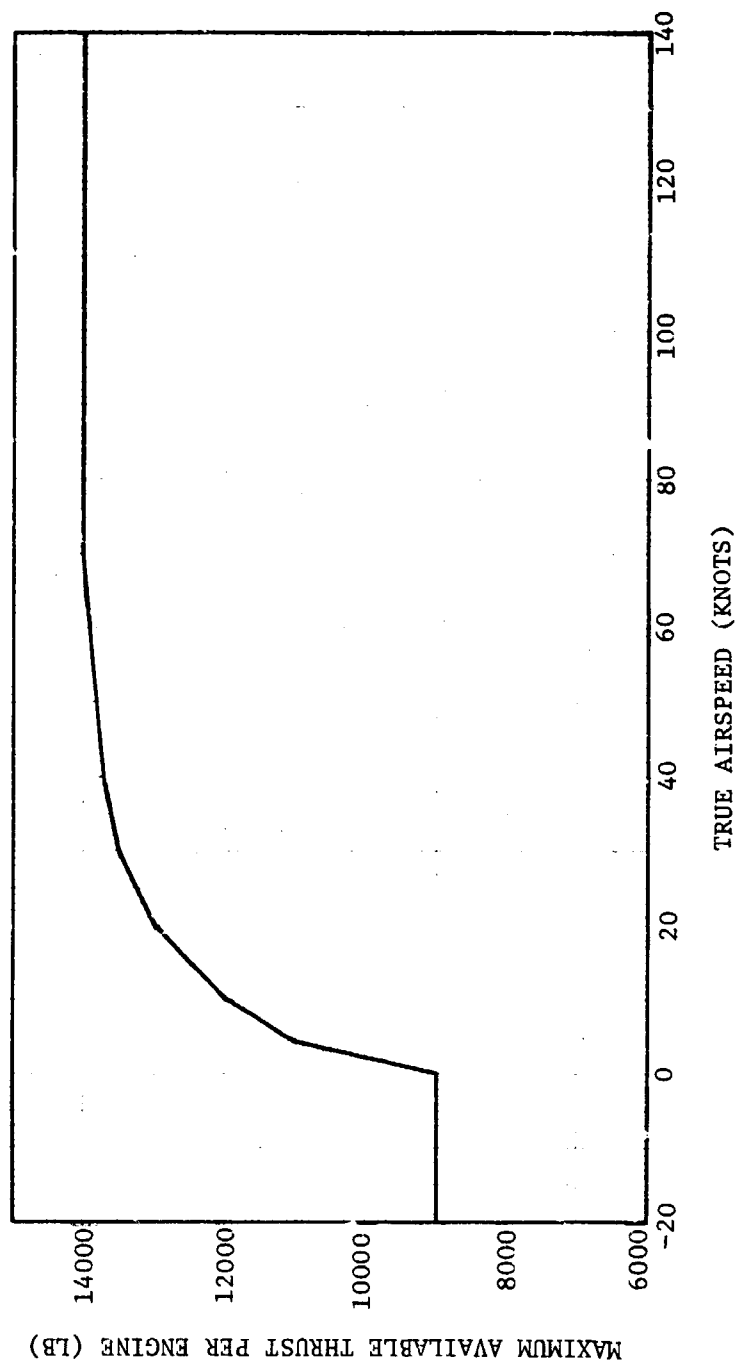


Figure 113 Boeing 367-80 Engine Takeoff Thrust as a Function of True Airspeed

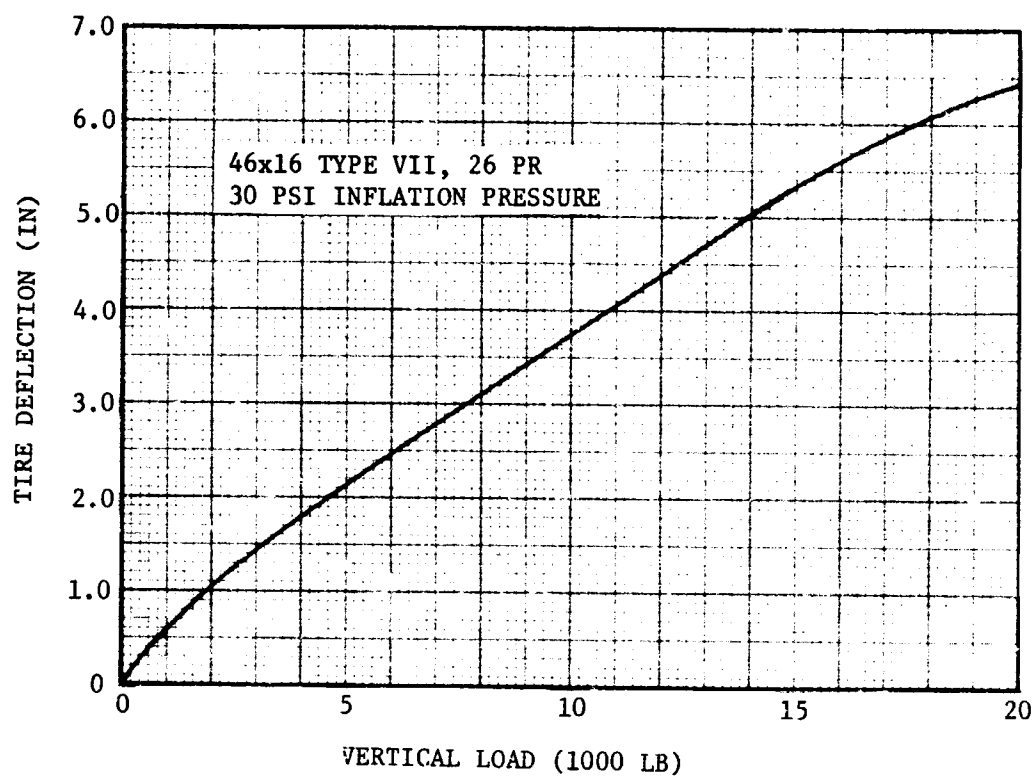


Figure 114 Boeing 367-80 Main Gear Tire Deflection Curve

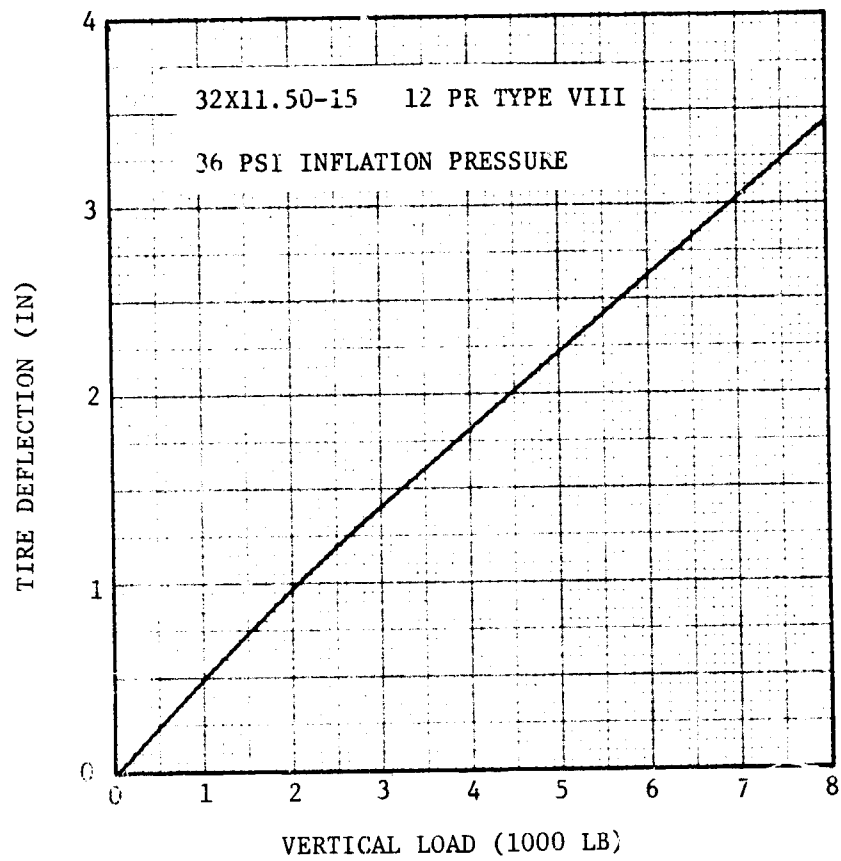


Figure 115 Boeing 367-80 Nose Gear Tire Deflection Curve

## APPENDIX E

### DATA USED TO DESCRIBE THE LOCKHEED C-141 AIRCRAFT

1. Discussion - This appendix gives basic data used in the computer program to make the soil takeoff performance assessment of Section V. The data was obtained from contractor reports and discussion with personnel in the C-141 Systems Program Office at W-PAFB. Some of the data was taken directly from Reference 4 and an attempt to correlate takeoff distance on paved surfaces was made with the results contained therein. Some difficulty was encountered, however, since thrust values are in terms of Engine Pressure Ratio (EPR) and not as installed thrust as required by the present program. The velocity for takeoff was calculated from Equation (24) using Lockheed  $C_{LMAX}$  values obtained from the stall prevention system operation.

$$V_{to} = \kappa \sqrt{\frac{2W}{\rho \bar{S} C_{LMAX}}} \quad (24)$$

where:  $V_{to}$  = Velocity required for takeoff (ft/sec)

$W$  = Vehicle gross weight (lbs)

$\bar{S}$  = Wing Area (sq ft)

$\rho$  = Atmospheric density ( $\frac{lb \text{ sec}^2}{ft^4}$ )

$\kappa$  = Takeoff speed safety factor (varies from 1.1 to 1.5)

$C_{LMAX}$  = Lift coefficient for stall = 1.975

The stall speeds were increased by factors of 1.1 to 1.5 from Figure 121 depending on the thrust to weight ratio. The results are shown in Figure 120. Takeoff criteria used in this study was to obtain liftoff speed. The values of speed and gross weight used in the analysis are given in Table 12. The center of gravity variation with gross weight was converted to distance forward of the main landing gear strut as in Appendix D. This variation is shown in Figure 116. Since the C-141 aircraft is not a high flotation configuration as was the Boeing 367-80, much higher sinkage and drag ratio values should be expected. To check the effect of tire pressure on the performance capability, calculations were made for tire pressures lower than the rated value shown in the following section. These tire pressure values are noted on specific curves given in Section V. The remaining information is presented in tabulated form on the following page.

C-141 Aircraft Data

Item	Symbol Used in Computer Program	Value
Number of Main Landing Gear Tires	WMG	4 per strut
Width of Main Gear Tire	BM	15.68 in.
Diameter of Main Gear Tire	DM	42.85 in.
Main Gear Tire Section Height	HTM	12.22 in.
Number of Nose Landing Gear Tires	WNG	2
Width of Nose Gear Tires	BN	11.45 in.
Diameter of Nose Gear Tires	DN	34.61 in.
Nose Tire Section Height	HTN	9.3 in.
Number of Main Gear Tandem Wheel Sets	NTANDM	2 per strut
Number of Nose Gear Tandem Wheel Sets	NTANDN	0
Distance between Nose and Main Gear Strut	DWB	53 ft.
Distance Between Main Gear Strut and c.g.	DCG	See Figure 116
Gross Weight of Vehicle	W	140-316.1 KIP
Wing Area	AW	3228 Sq. Ft.
Lift Coefficient During Takeoff 25° Flap	CL	0.82
Drag Coefficient During Takeoff 25° Flap	CD	0.055
Atmospheric Density Ratio	SIG	1
Slope of Runway	SLOPE	0 rad
Soil Density	RHOS	2.6 lb sec <sup>2</sup> /ft <sup>4</sup>
Clay Soil Strength	CI	150 to 500
Sand Soil Strength	G	45 to 200
Paved Surface Friction Coefficient	RPC	0.015
Number of Engines	NENGs	4

# C-141 Aircraft Data (Cont'd)

Item	Symbol Used in Computer Program	Value
Thrust of Engines	XVEL, YTH	See Figure 117
Velocity Required for Takeoff	VTO	See Table 12
Soil Type	NTYP	Clay and Sand
Load Deflection Curve For Main Gear Tire (44x16 type VII, 28 PR 130 PSI Inflation)	XFVM, YDFM	See Figure 118
Load Deflection Curve for Nose Gear Tire (36x11 Type VII, 22 PR, 140 PSI Inflation)	XFVN, YDFN	See Figure 119

TABLE 12  
C-141 TAKEOFF SPEED

Gross Weight 1000 lbs	Speed for 25° Flap*	
	Ft/Sec	Knots
316.1	238.28	141.10
300	231.5	137.09
280	223.68	132.45
260	217.02	128.51
240	209.9	124.29
220	202.97	120.19
200	195.49	115.76
180	189.77	112.37
160	189.87	112.43
140	194.6	115.25

\* Speeds correspond to handbook lift-off speed

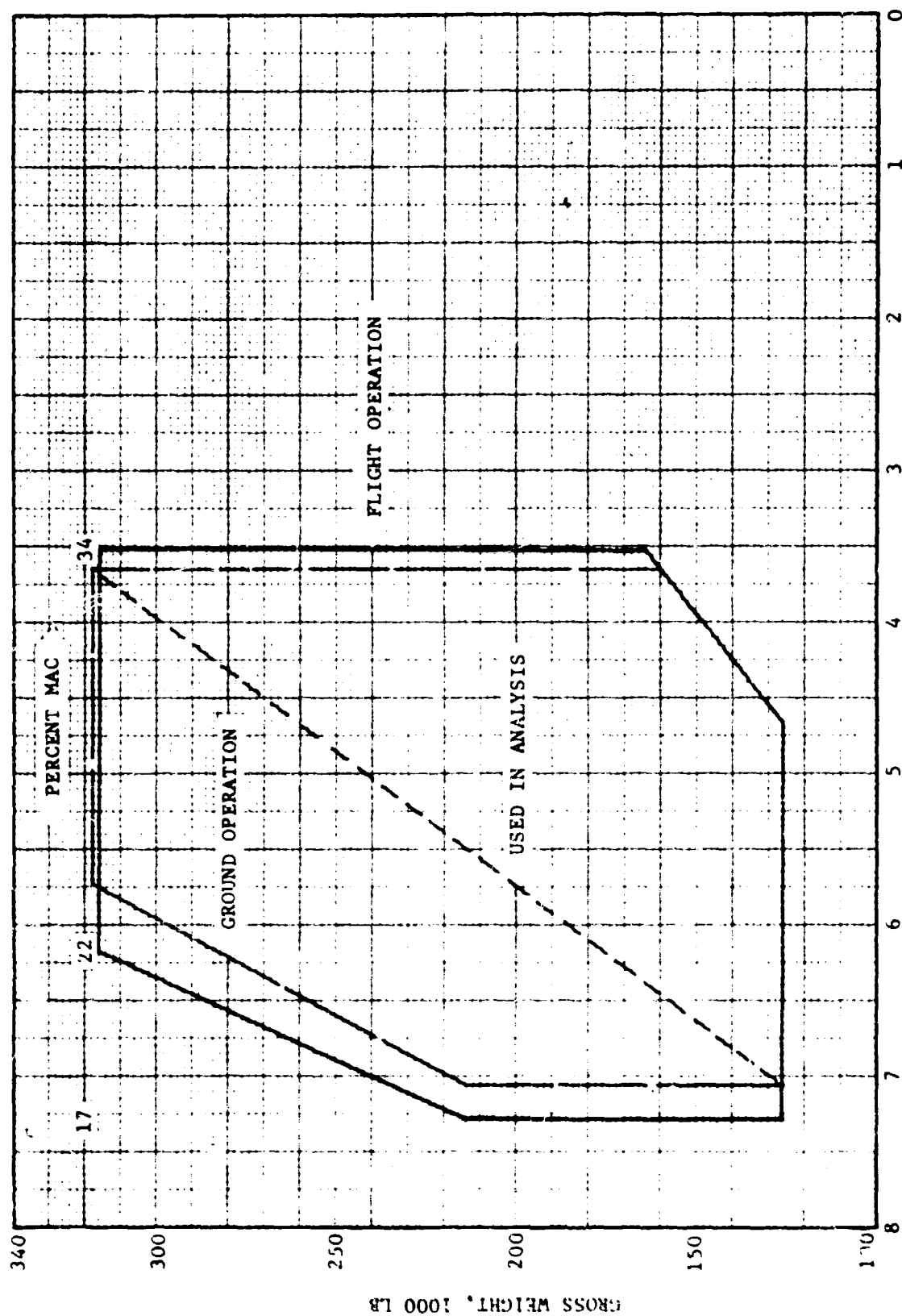


Figure 116 CG Location as a Function of Gross Weight for C-141 Aircraft

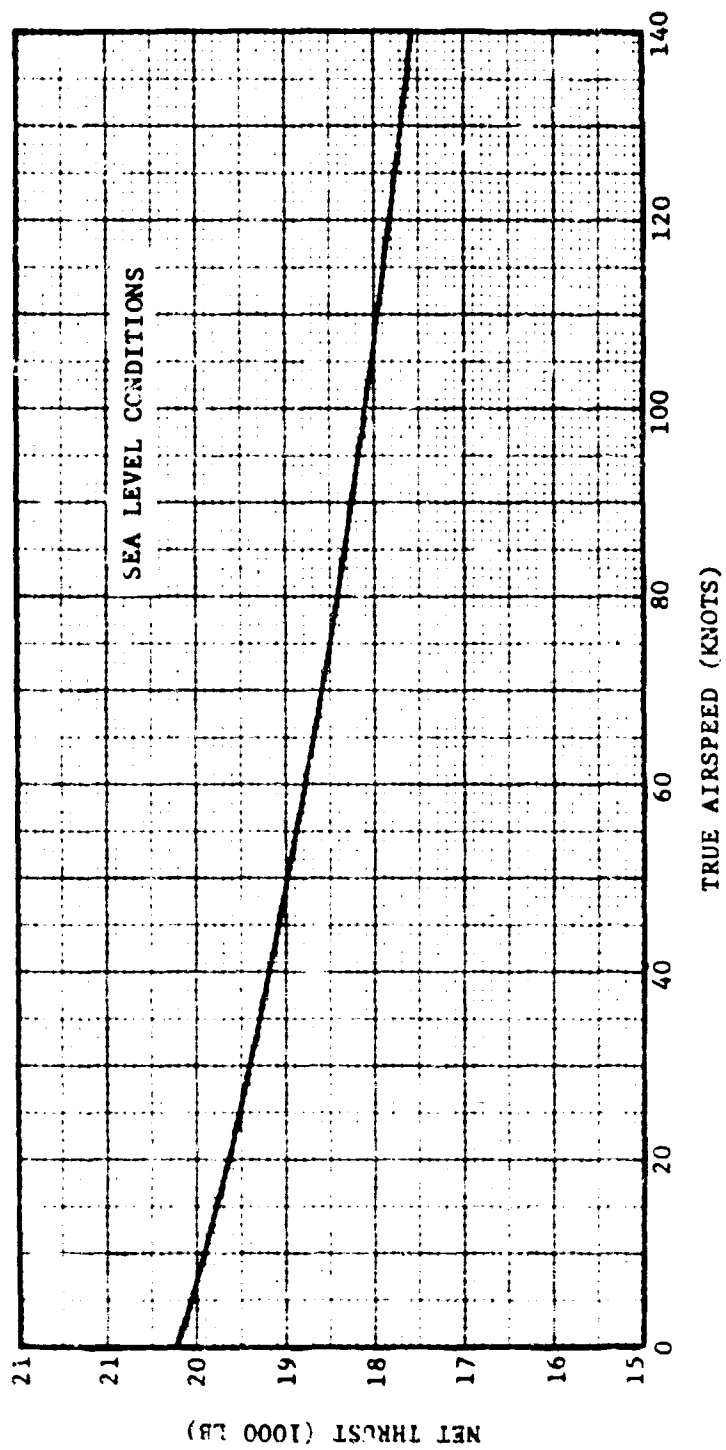


Figure 117 C-141 Takeoff Thrust as a Function of True Airspeed

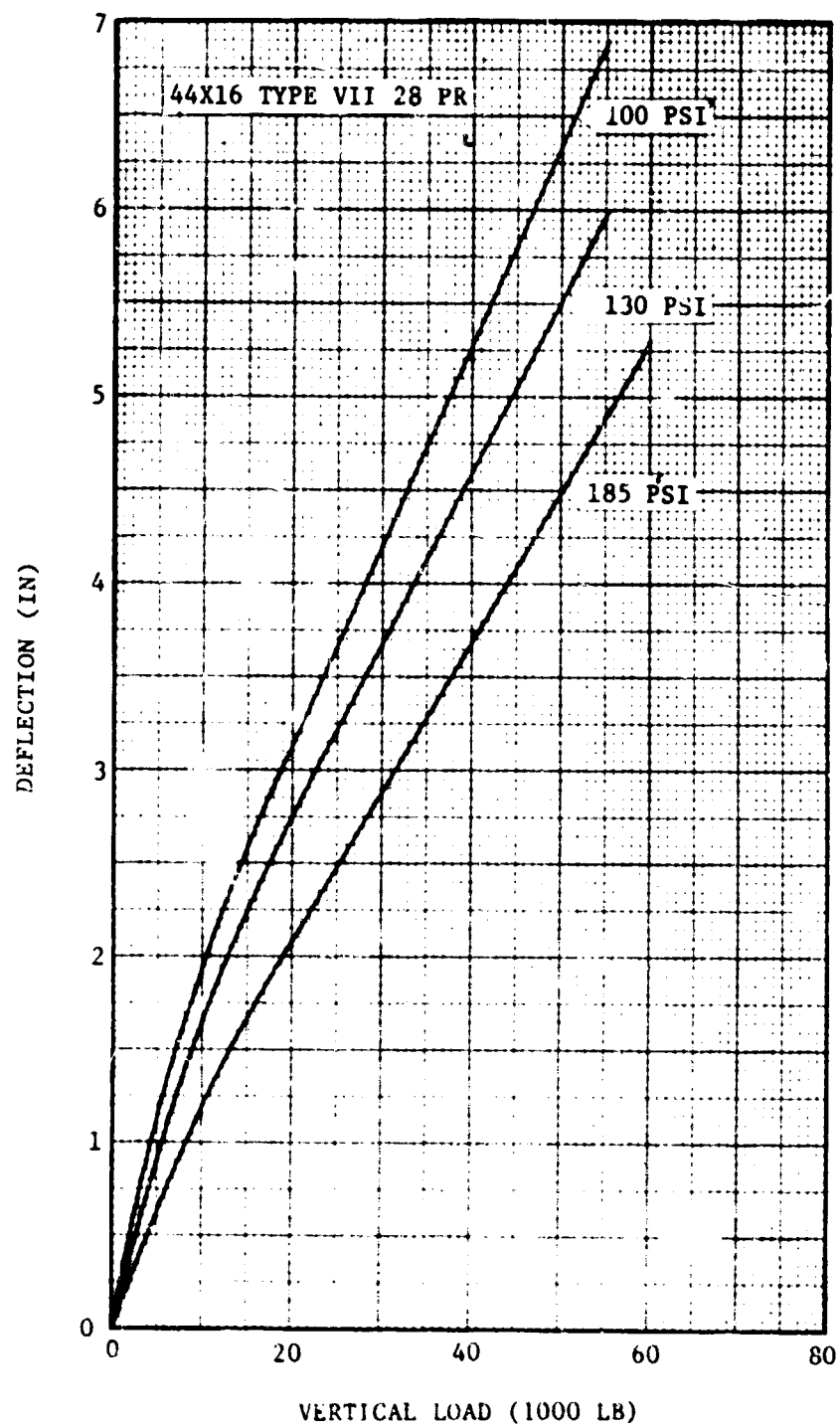


Figure 118 C-141 Main Gear Tire  
Deflection Curve

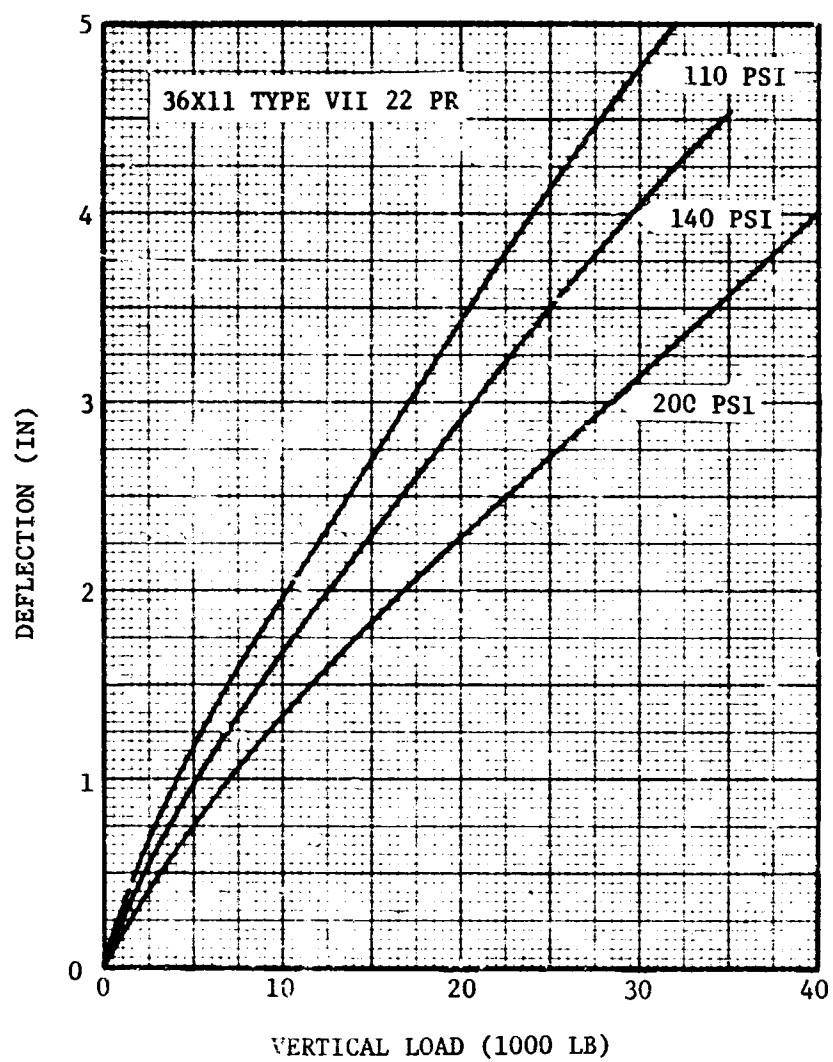


Figure 119 C-141 Nose Gear Tire Deflection Curve

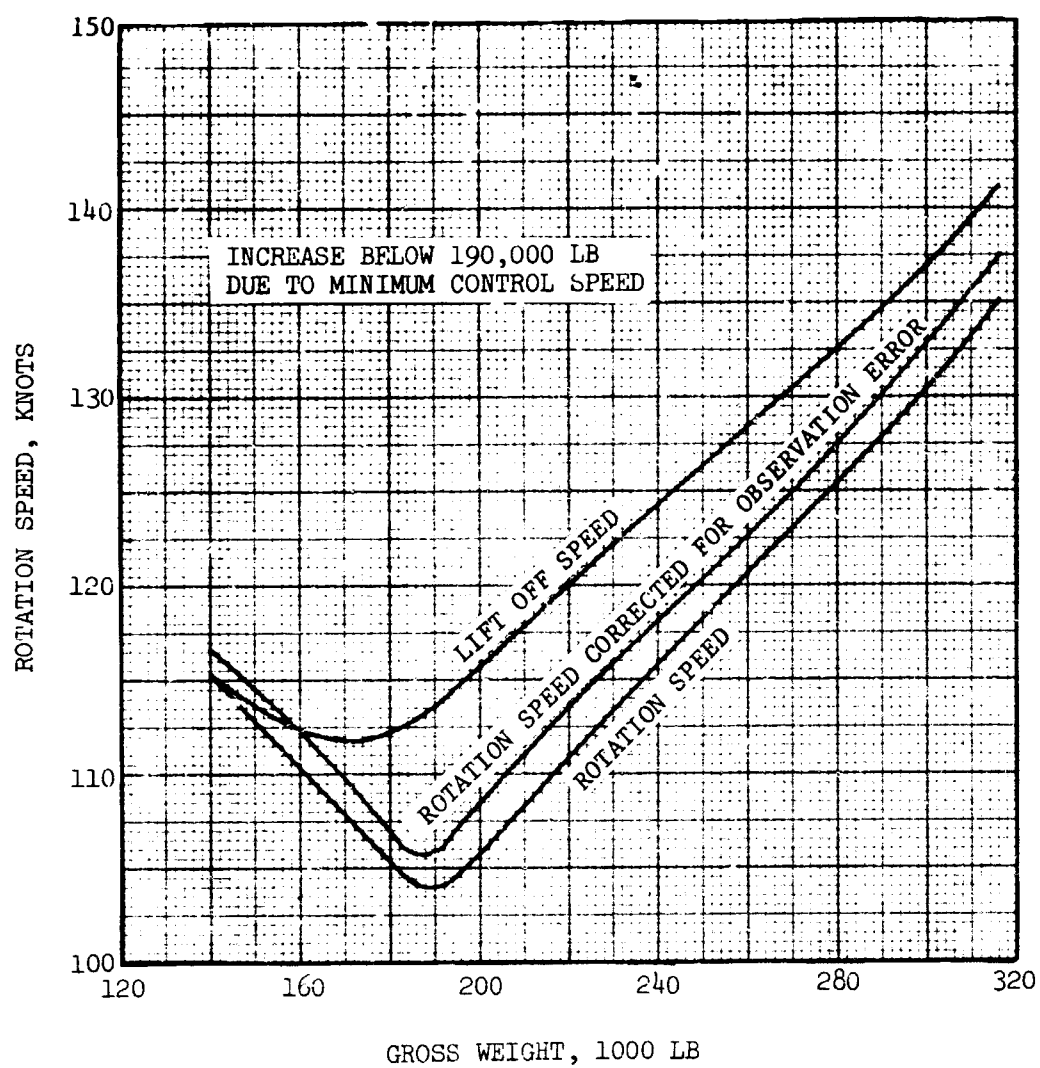


Figure 120 Takeoff Speed as a Function of Gross Weight  
for C-141 Aircraft

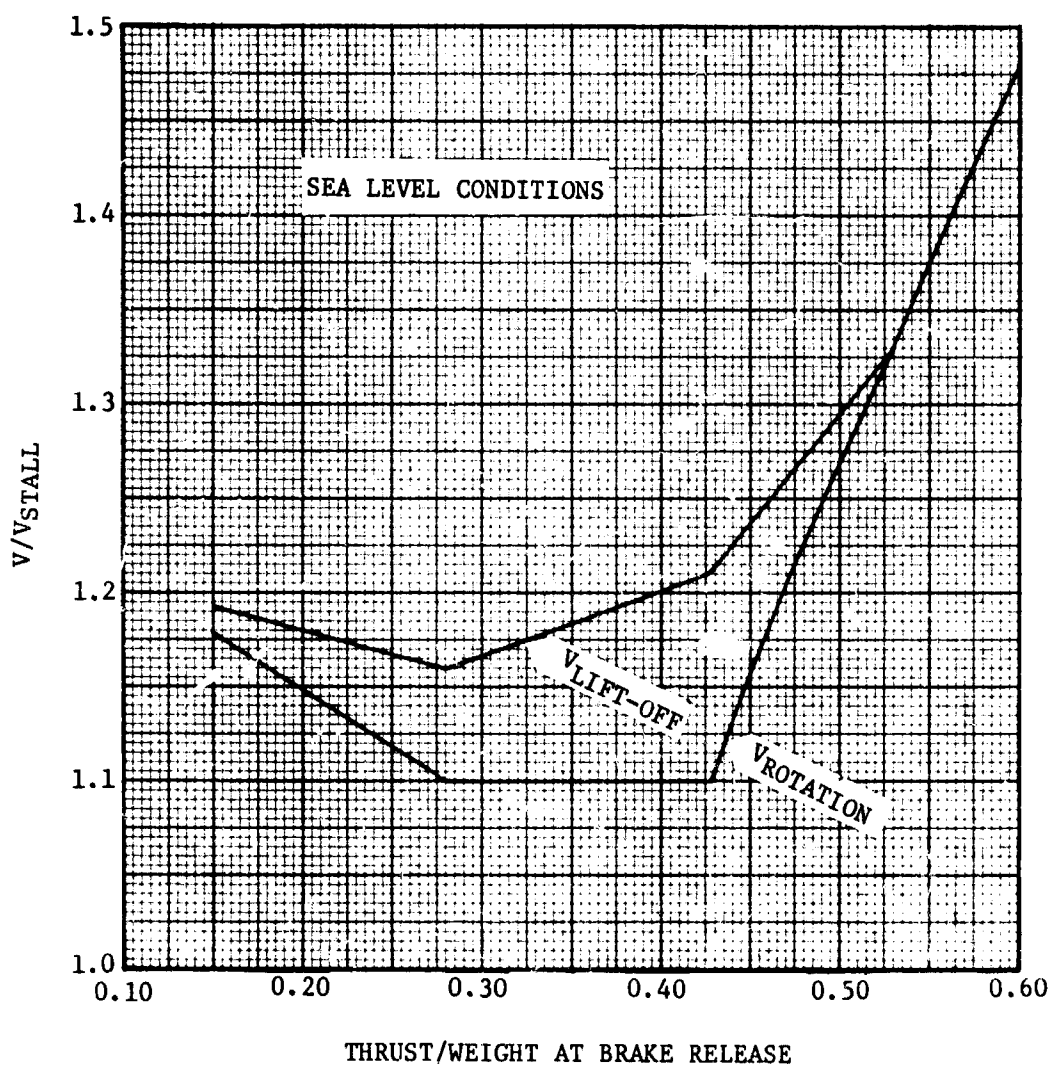


Figure 121 Takeoff Speed as a Function of Thrust to Weight Ratio

## APPENDIX F

### DATA USED TO DESCRIBE THE LOCKHEED C-5 AIRCRAFT

1. Discussion - This appendix gives data used in the computer program to make the soil takeoff performance calculations which appear in Section VI. The data was obtained from discussion with the C-5 Systems Program Office and from contractor reports. The stall speed was determined in the usual manner by equation 25 and increased by a factor of 1.17 to obtain takeoff speed. Table 13 shows the results for a range of gross weights.

$$V_{\text{stall}} = \sqrt{\frac{2W}{\rho \bar{S} C_{L\text{MAX}}}} \quad (25)$$

$$V_{\text{to}} = \kappa V_{\text{stall}} \quad (26)$$

where:  $V_{\text{to}}$  = Velocity required for takeoff (ft/sec)

$W$  = Vehicle gross weight (lb)

$\bar{S}$  = Wing Area (sq ft)

$\rho$  = Atmospheric density  $\left(\frac{\text{lb sec}^2}{\text{ft}^4}\right)$

$\kappa$  = Takeoff speed safety factor (1.17 all weights)

$C_{L\text{MAX}}$  = Lift coefficient for stall = 2.48 for 25° flap  
in takeoff configuration.

The center of gravity variation with gross weight was converted to distance forward of the effective main gear strut and is given as Figure 122. This concept of assuming that both main gear trucks are mounted on a common strut was chosen for convenience since the program was designed assuming only one set of main gear struts. This approximation gives higher nose gear loads and equal main gear loads. The overall effect of this assumption was not investigated in detail, however, it was felt that results would be representative of the actual performance as long as the correct total gross weight was used. The remaining data is presented in tabular form on the following page.

C-5 Aircraft Data

<u>Item</u>	<u>Symbol Used in Computer Program</u>	<u>Value</u>
Number of Main Landing Gear Tires	WMG	12 per side
Width of Main Gear Tire	BM	17.16 in.
Diameter of Main Gear Tire	DM	47.94 in.
Main Gear Tire Section Height	HTM	13.38 in.
Number of Nose Landing Gear Tires	WNG	4
Width of Nose Gear Tires	BN	17.16 in.
Diameter of Nose Gear Tires	DN	47.94 in.
Nose Tire Section Height	HTN	13.38 in.
Number of Main Gear Tandem Wheel Sets	NTANDM	6 per side
Number of Nose Gear Tandem Wheel Sets	NTANDN	0
Distance Between Nose and Main Gear Struts	DWB	72.93 Ft.
Distance Between Main Gear Strut and c.g.	DCG	See Fig. 122
Gross Weight of Vehicle	W	318.469-769 Kip
Wing Area	AW	6200 Ft <sup>2</sup>
Lift Coefficient During Takeoff, 25° Flap	CL	0.97
Drag Coefficient During Takeoff, 25° Flap	CD	0.0625
Atmospheric Density Ratio	SIG	1
Slope of Runway	SLOPE	0 rad
Soil Density	RHOS	2.6 $\frac{\text{lb sec}^2}{\text{ft}^4}$
Clay Soil Strength	CI	150 to 400

C-5 Aircraft Data (Cont'd)

<u>Item</u>	<u>Symbol Used in Computer Program</u>	<u>Value</u>
Sand Soil Strength	G	45 to 200
Paved Surface Friction Coefficient	RRC	0.025
Number of Engines	NENGs	4
Thrust of Engines	XVEL, YTH	See Fig. 123
Velocity Required for Takeoff	VTO	See Table 13
Soil Type	NTYP	Clay and Sand
Load Deflection Curve For Main Gear Tire (49x17 Type VII, 26 PR, 70 to 130 PSI Inflation)	XFVM, YDFM	See Figure 124
Load Deflection Curve for Nose Gear Tire (Same as Main)	XFVN, YDFN	See Figure 124

TABLE 13  
C-5 TAKEOFF SPEED

Gross Weight 1000 Pounds	Speed - Knots 25° Flap
800	149.0
700	139.0
600	127.5
500	114.5
400	102.5
300	89.0

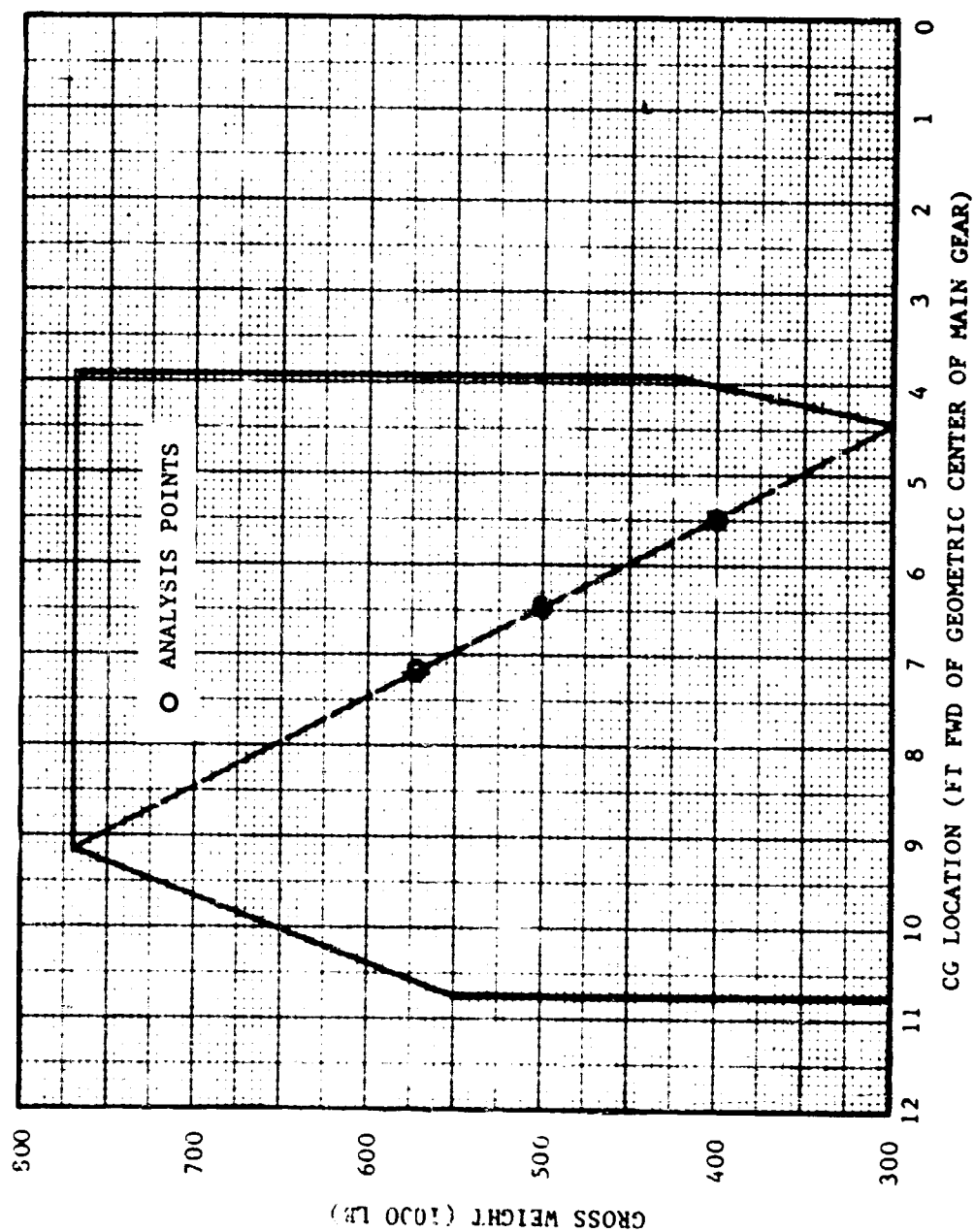


Figure 122 CG Location as a Function of Gross Weight for C-5 Aircraft

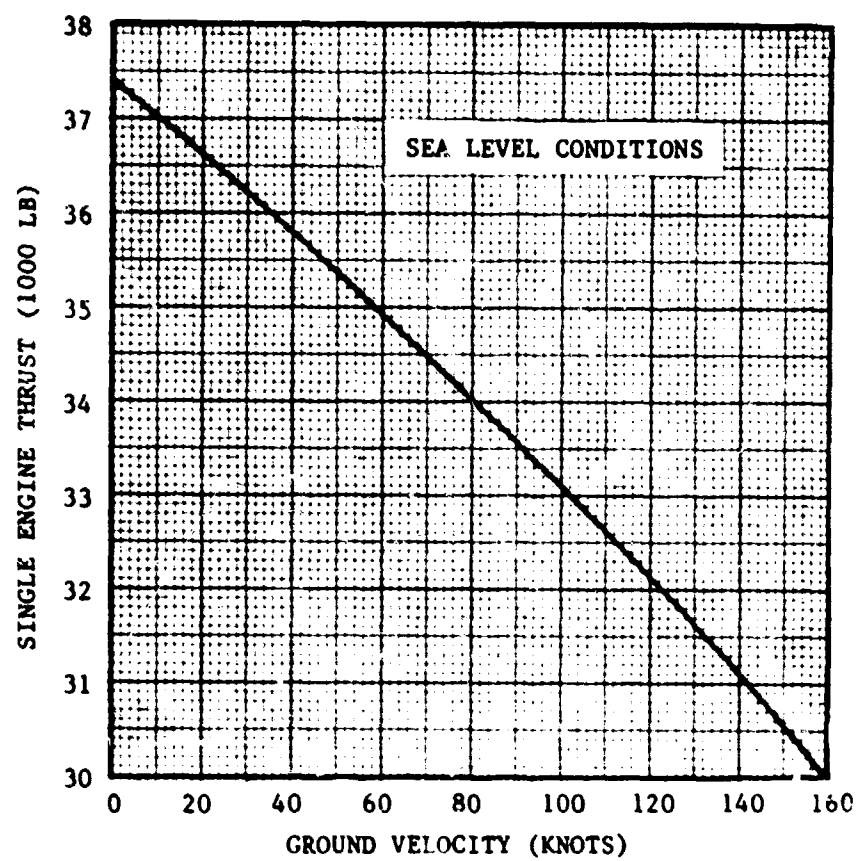


Figure 123 C-5 Single Engine Thrust as a Function of Ground Velocity

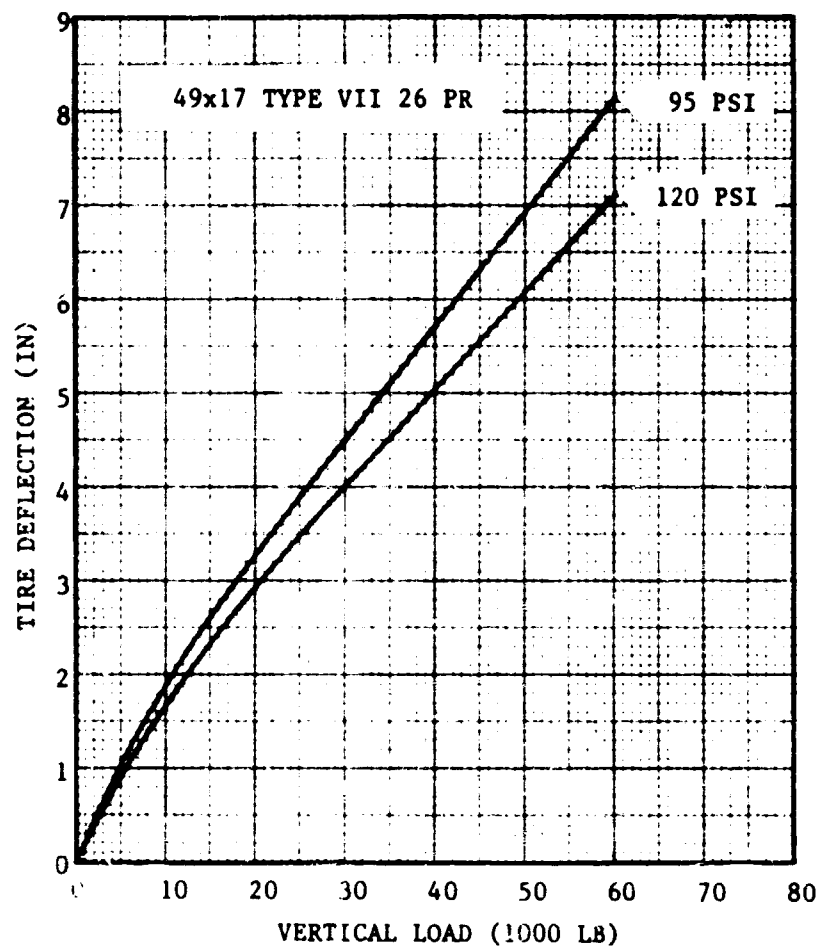


Figure 124 Deflection Curve for C-5 Main and Nose Gear Tires

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d.		
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13. ABSTRACT		
A prediction method for determining wheel sinkage, landing gear drag and takeoff performance on clay and sandy airfields is described. Three computer programs are presented along with computed results of C-141 and C-5 takeoff performance on clay and sand fields of varying soil strengths.		

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